D’une analyse ergonomique en situation réelle de travail à la mise en place d’un programme d’activités physiques adaptées pour la prévention des troubles musculo-squelettiques de la région lombaire de salariés viticoles

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FROM A FIELD ERGONOMIC WORK EXPOSURE ANALYSIS TO THE IMPLEMENTATION OF A WORKSITE ADAPTED PHYSICAL ACTIVITY PROGRAM FOR THE PREVENTION OF WORK RELATED MUSCULOSKELETAL DISORDERS OF THE LOW BACK AMONG VINEYARD-WORKERS

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From a field ergonomic work exposure analysis to the implementation of a worksite adapted physical activity program for the prevention of work related musculoskeletal disorders of the low back among vineyard-workers

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Romain Balaguier (RB) received his bachelor degree in sports sciences from the University of Grenoble Alpes in 2012 and a Master degree from the same university in 2014. Then, RB started in 2014 a joint PhD between the University of Grenoble Alpes and the University of Aalborg under the supervision of Doctor Nicolas Vuillerme, Professor Pascal Madeleine and Doctor Jacques Vaillant. This PhD thesis was supported by a grant of the French Ministry of Higher Education and Research. During his PhD thesis, RB participated in international scientific conferences such as the 9th International scientific conference on the prevention of Work-Related Musculoskeletal Disorders (PREMUS, Toronto, Canada, 2016) or such as the 22nd annual congress of the European college of sports science (ECSS, Essen, Germany, 2017). During his PhD thesis, RB was also in charge of the implementation of vocational training for occupational health among vineyard-workers for the project called “Well-being at work with adapted physical activities”.

Abstract

Work related musculoskeletal disorders (WMSDs) affecting the low back do represent one of the most pressing health problems and a major issue among workers in Europe including vineyard workers. It is noteworthy that the negative effects at the individual, employer and societal levels make the prevention of WMSDs affecting the low back a priority target in the viticulture sector. Within this context, the aim of this PhD thesis was to build an effective action to prevent WMSD symptoms of the low back among vineyard-workers.

A field ergonomic work exposure analysis was first conducted (i) to question the location and severity of WMSD symptoms and (ii) to objectively quantify the kinematics during pruning activity. Of note, this winter activity was chosen because it represents six months of the annual physical workload. To reach this first sub-objective, two complementary studies were conducted (Studies I and II). In Study I, self-reported musculoskeletal pain ratings confirmed the existing literature that the low back was the most painful anatomical region among vineyard-workers. In addition, two-dimensional video-recordings of pruning activity revealed that vineyard-workers frequently adopt trunk forward bending postures considered as 'extreme'. In Study II, the use of wireless tri-dimensional inertial sensors further demonstrated that pruning activity was also associated with trunk postures combining forward bending and rotation. On the whole, these two field studies indicated that vineyard-workers adopted trunk postures known to increase the risk of WMSD symptoms over the low back during the performance of pruning activity.

Based on these findings, a workplace supervised APA program was subsequently conceived, implemented and evaluated to specifically prevent WDMS symptoms of the low back among vineyard-workers. The APA program was supplementary to classical ergonomic interventions. To achieve this second objective, two complementary studies (Studies III and IV) were conducted in which volunteer vineyard-workers were invited to follow supervised warm-ups and training APA sessions targeting trunk muscle endurance and flexibility, known to decrease in case of WMSD symptoms over the low back. Results of Study III showed the effectiveness of this workplace supervised APA program to increase trunk muscle endurance and flexibility and to decrease pressure pain sensitivity over the low back, hence demonstrating the positive effects of APA on pain mechanisms. Results of Study IV further provided a comprehensive view on how and to what extent the context of the implementation of the APA program and the collaboration between stakeholders were decisive to reach a high compliance rate and were likely to increase the program's effectiveness.

As a whole, this PhD thesis demonstrated that, based on an ergonomic work exposure field analysis, a supervised workplace APA program can help to prevent WMSD symptoms of the low back among vineyard workers. Interestingly, even though the question of sustainability still remains to be assessed, these promising results have convinced other wine-producing companies to integrate this APA program as one component of their health policies already including ergonomic approaches.

Resumé

A ce jour, les troubles musculo-squelettiques (TMS) qui affectent la région lombaire sont considérés non seulement comme un problème majeur de santé au travail mais également comme un véritable problème de santé publique. Même si tous les secteurs d'activité sont touchés, l'agriculture et notamment la viticulture concentrent un nombre important de ces atteintes à la santé. En conséquence, ce travail de thèse doctoral avait pour objectif de construire au sein d'entreprises vini-viticoles une action efficace destinée à prévenir les symptômes associés aux TMS de la région lombaire. Pour répondre à cet objectif, deux actions ont été successivement menées.

Dans un premier temps, une analyse ergonomique en situation réelle de travail a été réalisée. Cette dernière s'est déroulée pendant l'activité de taille, activité qui représente presque six mois de travail et qui détermine le bon déroulement et la qualité des autres activités. L'analyse ergonomique avait tout d'abord pour objectifs d'identifier les localisations anatomiques douloureuses et répertorier la sévérité des symptômes associés. Ensuite, cette dernière a évalué de façon objective les exigences physiques auxquelles étaient confrontés les vigneronness et vignerons pendant l'activité de taille. Afin de répondre à ces objectifs, deux études complémentaires (Etudes I et II) ont été réalisées. Dans l'Etude I, la localisation et l'intensité des douleurs auto-rapportées par les vigneronnes et vignerons a confirmé les résultats de plusieurs études sur cette population, à savoir que la région lombaire était la localisation anatomique la plus fréquemment affectée et la plus douloureuse. De façon plus originale, l'Etude I, a également mis en évidence, à partir d'enregistrements vidéo que l'activité de taille était associée à des flexions du tronc considérées comme « extrêmes » dans la littérature. Dans l'Etude II, l'utilisation de capteurs embarqués a permis de démontrer que l'activité de taille associait flexions et rotations du tronc. Au final, ces deux études réalisées en conditions réelles de travail ont montré que pendant l'activité de taille, les vigneronnes et vignerons présentaient des douleurs importantes au niveau de la région lombaire et que cette activité les exposait à un risque important de survenue de TMS au niveau de cette région anatomique.

Sur la base de ces résultats et de l'inefficacité des actions menées jusque là, la construction d'une action de prévention des TMS de la région lombaire semblait nécessaire. Pour ce faire deux études (Etudes III et IV) ont été réalisées. Ces dernières avaient pour objectifs de développer, mettre en place et évaluer un programme d'activités physiques adaptées (APA) destiné à améliorer l'endurance des muscles fléchisseurs et extenseurs du tronc ainsi que la souplesse du rachis. Les résultats de l'Etude III menée au sein d'une entreprise vini-viticole ont tout d'abord montré que le programme d'APA conduisait à une augmentation de ces capacités neuro-musculaires. En parallèle, l'Etude III a démontré l'efficacité du programme d'APA pour diminuer la sensibilité à la pression au niveau de la région lombaire. Les résultats de l'Etude IV ont non seulement confirmé à plus grande échelle les résultats de l'Etude III mais ont également mis en évidence à l'aide d'une évaluation des procédés que le contexte dans lequel s'est déroulée l'intervention avait grandement contribué à l'efficacité du programme.

Finalement, l'ensemble des travaux présentés dans cette thèse de doctorat a montré qu'une analyse ergonomique était une condition préalable et indispensable au développement d'actions destinées à prévenir les TMS. Il a également été démontré que la promotion d'une activité physique sur le lieu de travail adaptée aux exigences professionnelles et aux individus

constituait une piste de travail prometteuse pour la prévention des TMS de la région lombaire dans le secteur viticole.

Dansk Sammenfatning

Arbejdsrelaterede muskuloskeletale lidelser (work-related musculoskeletal disorders, WMSD) i lænden er et stort sundhedsmæssigt problem blandt arbejdere i Europa inklusive arbejdere på vingårde. Det er bemærkelsesværdigt, at vinsektoren har fokus på de negative virkninger af WMSD for både den enkelte arbejder, arbejdsgiverne og samfundet og at man prioriterer forebyggelsen af WMSD. Set I lyset heraf var formålet med denne ph.d.-afhandling at gennemføre et effektivt program til forebyggelse af WMSD-symptomer i lænden hos arbejdere på vingårde.

Først udførtes en feltanalyse af de ergonomiske arbejdsforhold (i) for at fastlægge placeringen og omfanget af WMSD-symptomerne og (ii) for objektivt at kvantificere kinematikken under beskæringsarbejde. Det skal understreges, at denne vinteraktivitet blev valgt, da den repræsenterer det halve af årets fysiske arbejdsbelastning. Til at opnå dette første del-formål, blev der udført to studier (Studie I og II). I Studie I bekræftede selv-rapporterede muskuloskeletale smertevurderinger, i overensstemmelse med den eksisterende litteratur, at lænden er det kropsområde, hvor vinarbejdere oplever størst smerte. Desuden afslørede todimensionelle videooptagelser af beskæringsarbejdet, at vinarbejdere ofte indtager foroverbøjede kropspositioner, der betegnes som "ekstreme". I Studie II afslørede trådløse tredimensionelle inerti-sensorer endvidere, at beskæringsaktiviteten også var forbundet med kropsholdninger, der kombinerer foroverbøjning og rotation. Alt i alt viste disse to feltstudier, at arbejdere på vingårde indtager kropsholdninger, som vides at forøge risikoen for WMSD-symptomer i lænden under beskæringsarbejde.

Baseret på disse resultater blev et arbejdsplads-superviseret og tilpasset fysisk aktivitetsprogram (APA-program; APA = adapted physical activity) udarbejdet, implementeret og efterfølgende evalueret. Programmet blev målrettet mod at forhindre WMSD-symptomer i lænden hos arbejdere på vingårde. APA-programmet skulle ses som et supplement til de klassiske ergonomiske interventioner. Derfor blev der udført yderligere to studier (Studie III og IV), hvor frivillige vinarbejdere skulle følge superviseret opvarmning og et APA-program med fokus på udholdenhed og fleksibilitet i overkroppens muskler. Resultaterne af Studie III viste virkningen af det arbejdsplads-superviserede APA-program i form af forbedret muskeludholdenhed og –fleksibilitet og formindsket tryksmertefølsomhed i lænden. Hermed beviste studiet de positive effekter af APA-programmet på smertemekanismer. Endvidere gav resultaterne af Studie IV et udførligt overblik over, hvordan og i hvilken grad konteksten for implementeringen af APA-programmet og samarbejdet mellem de medvirkende parter var afgørende for at opnå høj effektrate og sandsynligvis var var i stand til at forøge programmets virkning.

Denne ph.d.-afhandling viste derfor, at analyser af arbejdsforhold udført in situ og et superviseret APA-program på arbejdspladsen kan bidrage til at forhindre WMSD-symptomer hos arbejdere på vingårde. Det er interessant, at selv om spørgsmålet om virkningen oven tid mangler at blive vurderet, har disse lovende resultater medvirket til at overbevise andre vinfirmaer til at integrere APA-programmer i deres sundhedspolitik, idet de allerede har indført ergonomiske tiltag i arbejdsprocesserne.

Resumé long

Les troubles musculo-squelettiques (TMS) sont définis comme des atteintes douloureuses de l'appareil locomoteur qui peuvent toucher muscles, nerfs, tendons ou articulations. Ces atteintes sont très fréquentes dans le secteur agricole, notamment dans le secteur viticole. A titre d'exemple, plus de 60% des travailleurs de ce secteur déclarent ressentir des douleurs au niveau du rachis lombaire et 30% au niveau du membre supérieur. Ces chiffres font aujourd'hui de la viticulture le secteur agricole le plus touché par les TMS en France. L'ampleur de ce problème peut également s'apprécier au regard des données publiées régulièrement par la Mutualité Sociale Agricole (MSA), la sécurité sociale du secteur agricole. Les TMS représentent, depuis plusieurs années, la grande majorité des maladies professionnelles reconnues et indemnisées par la MSA. Elles sont notamment aujourd'hui responsables en agriculture de près de 800 000 journées de travail perdues chaque année, et en viticulture de près de 40 millions d'euros de versement d'indemnités journalières. Dans ce contexcte, les TMS sont au centre d'enjeux économiques et sociétaux importants qui incitent employeurs et pouvoirs publics à se saisir de ce problème de santé publique majeur. A ce jour, néanmoins, force est de constater que les démarches engagées restent encore insuffisantes face à l'ampleur du problème. En effet, sur une période de 10 ans entre 2000 et 2010, le nombre de TMS pour le secteur viticole a été multiplié par 5 et augmente régulièrement d'environ 1,6% par an. De plus, l'allongement de la vie professionnelle, le vieillissement de la population salariée et le difficile renouvellement du personnel dans ce secteur ne laissent présager d'une évolution favorable à court terme. Au regard de ces chiffres, la prévention des TMS constitue aujourd'hui un enjeu majeur dans le secteur viticole. La question est alors de savoir quoi mettre en place et comment organiser une action de prévention des TMS efficace et durable pour ce secteur.

Nombreux sont les auteurs qui s'accordent à dire que mieux comprendre l'origine des TMS, c'est-à-dire mieux appréhender les mécanismes liés à leur apparition, constitue une première étape indispensable et déterminante dans la prévention de ces atteintes à la santé. En ce sens et depuis près de 30 ans, il est important de mettre en avant les efforts des chercheurs et cliniciens à ce sujet. Il a ainsi été démontré que, dans plusieurs secteurs d'activité dont la viticulture, la conjugaison de plusieurs facteurs de risque, de nature individuels, biomécaniques, psychosociaux et organisationnels, est à l'origine du risque de survenue de TMS. Citons par exemple, l'avancée en âge qui est l'un des facteurs de risque individuel les plus importants de survenue de TMS dans le secteur viticole, puisque les travailleurs âgés de 40 à 50 ans, qui représentent seulement 20% de la population salariée, déclarent environ 70% des TMS de ce secteur. Les travaux de Roquelaure et al. (2001, 2002, 2004) ont également démontré que certaines activités réalisées par les vigneronnes et vignerons sont complexes et nécessitent la réalisation de mouvements répétitifs et en force du membre supérieur. Ces auteurs ont rapporté que pendant l'activité de taille de la vigne, les vigneronnes et vignerons donnent en moyenne plus de 30 coups de sécateurs par minute et réalisent des mouvements de déviation ulnaire ou radiale considérés comme « extrêmes ». Les travaux de Bernard et al (2011) ont par ailleurs mis en évidence qu'une faible latitude décisionnelle et que le manque de marge manœuvre constituent des risques psychosociaux auxquels les vigneronnes et vignerons sont fréquemment exposés.

Dès lors, quantifier l'exposition à ces différents facteurs de risque constitue la seconde étape nécessaire à la mise en place d'une action efficace de prévention des TMS. Pour ce faire, il s'agit d'analyser les situations de travail et le contexte dans lequel salariés et entreprises évoluent. Cette analyse doit permettre d'appréhender de manière globale les situations de travail, d'identifier les activités les plus à risque pour *in fine* adapter les actions à mettre en place et donc transformer les situations de travail.

Dans le secteur viticole, les transformations proposées portent principalement sur le matériel professionnel et consistent en des évolutions techniques et technologiques destinées à prévenir principalement les TMS du membre supérieur. Par exemple, au cours de ces dernières années, une des transformations les plus marquantes a été opérée sur les sécateurs utilisés par les vigneronnes et vignerons. Les sécateurs manuels sont en effet aujourd'hui dotés d'une poignée tournante et d'une géométrie de lame optimisée. Ces modifications permettent, pendant l'activité de taille d'augmenter le temps passé dans des angulations neutres pour le poignet (Roquelaure et al. 2004), c'est-à-dire des angulations moins à risque de survenue de TMS. Les améliorations techniques opérées pour la prévention des TMS du membre supérieur semblent toutefois difficilement réplicables pour les TMS qui affectent le rachis. Pour ces derniers qui représentent une part tout aussi importante des TMS dans le secteur viticole, il semble en effet que les évolutions techniques telles que le déploiement de siège de vigne, ne soient pas encore en mesure de répondre correctement aux conséquences individuelles, professionnelles et sociétales que ce type de pathologies engendre.

Dans ce contexte, ce travail de thèse de doctorat avait pour objectif de concevoir, mettre en œuvre et évaluer, au sein d'entreprises vini-viticoles, une action efficace destinée à prévenir les symptômes associés aux TMS de la région lombaire. Pour répondre à cet objectif, nous avons suivi une démarche en deux temps.

Dans un premier temps, une analyse ergonomique en situation réelle de travail a été conduite. Cette dernière s'est déroulée pendant l'activité de taille, activité hivernale primordiale, qui détermine aussi bien la qualité que la quantité de raisins produits et conditionne le bon déroulement des autres activités réalisées tout au long de l'année. L'analyse ergonomique menée dans l'étude 1, avait tout d'abord pour objectif d'identifier les localisations anatomiques perçues douloureuses et de côter la sévérité des symptômes associés. Pour répondre à cet objectif, 5 vigneronnes et 6 vignerons ont reporté deux fois par jour (avant et après la journée de travail) pendant une semaine de travail complète (du lundi au vendredi) l'intensité de leurs douleurs perçues au niveau de 22 localisations anatomiques. La localisation et l'intensité des douleurs auto-rapportées par les vigneronnes et vignerons ont confirmé les résultats d'études antérieures sur cette population, à savoir que la région lombaire représentait la localisation anatomique la plus fréquemment affectée et la plus douloureuse. Ces résultats ont également montré que l'intensité des douleurs perçues au niveau du rachis lombaire augmentait significativement entre le début et la fin de semaine de travail, ce qui suggère que l'activité de taille *per se* augmente le risque de TMS au niveau du rachis lombaire. Pour cette activité, Bernard et al (2011) ont également reporté un risque plus élevé de TMS du rachis lombaire. Ils ont en outre avancé l'idée selon laquelle les contraintes physiques, notamment les postures adoptées par les vignerons, ainsi que la position des batteries des sécateurs électriques au bas du dos, pouvaient, en partie, contribuer à l'augmentation des risques de survenue de TMS au niveau du rachis lombaire. Cependant, aucune étude en situation réelle de travail n'a depuis confirmé de façon objective ces hypothèses. Fort de cette conclusion, l'Etude I a ensuite évalué de façon objective les exigences physiques auxquelles étaient confrontés les vigneronnes et vignerons pendant l'activité de taille. Pour ce faire, ces derniers ont été filmés et une analyse de la cinématique centrée sur l'angle tronc cuisse a été ensuite réalisée. Les résultats ont permis de confirmer que pendant l'activité de taille, les vigneronnes et vignerons adoptent des postures à risque de TMS au niveau du rachis lombaire. En effet, l'activité de taille est associée à des flexions du tronc considérées comme « extrêmes » dans la littérature scientifique. Cependant, même si l'Etude I a permis de quantifier de manière objective l'exposition à un facteur de risque, à savoir l'adoption de postures « extrêmes », cette dernière présente aussi une limite importante. En effet, il a été démontré que l'utilisation de la vidéo comme méthode d'observation peut, en fonction du placement de l'observateur notamment, conduire non seulement à des imprécisions de mesure, mais aussi à ne pas être en mesure de quantifier certains facteurs de risque. Par exemple, il est aujourd'hui avéré que les mouvements de rotation du tronc, bien qu'identifiés comme facteurs de risque de TMS, sont difficilement quantifiables par analyse vidéo *in situ*. Aussi, pour compléter les résultats de l'Etude I, 9 vignerons et 6 vigneronnes, équipés d'un capteur inertiel (I4 motion, Technoconcept, Mane, France; fréquence d'échantillonnage: 100 Hz), placé au niveau du sternum pendant la réalisation de l'activité de taille, ont participé à l'Etude II. Ce capteur accélérométrique tridimensionnel est plus précis que la vidéo pour l'analyse de postures dynamiques et présente l'avantage de pouvoir quantifier la rotation du tronc. Le temps passé avec des flexions du tronc inférieures à 30°, supérieures à 60° et 90°, ainsi que le temps passé à adopter des rotations du tronc inférieures à 10°, supérieures à 10° et supérieures à 30°, a été calculé de manière automatique à partir des signaux des capteurs inertiels. Ces angles « seuils » sont communément utilisés dans la littérature scientifique. L'analyse des données des capteurs inertiels obtenues après 12 minutes de taille ont confirmé les résultats de l'Etude I, à savoir que cette activité était associée à des flexions du tronc sur de longues périodes. En effet, les vigneronnes et vignerons ont passé près de 58% et 20% des 12 minutes avec le tronc fléchi respectivement à plus de 30° et 60°. Ces pourcentages sont en moyenne trois fois supérieurs à ceux observés dans d'autres secteurs d'activités tels que le secteur hospitalier ou le secteur industriel également connus pour leur prévalence élevée de TMS au niveau du rachis lombaire. Il a été difficile de trouver d'autres secteurs d'activités qui exposent les travailleurs à des flexions du tronc aussi importantes sur d'aussi longues périodes. Cependant, il semble que les résultats reportés dans l'Etude II se rapprochent de ceux observés auprès de professionnels de la petite enfance ou encore de professionnels du secteur automobile tels que les garagistes. De manière originale, les résultats de l'Etude II ont en outre montré que l'activité de taille associait flexions et rotations du tronc puisqu'au cours des 12 minutes de taille, les vigneronnes et vignerons ont travaillé en moyenne 50% du temps avec des rotations du tronc supérieures à 10°.

Dans leur ensemble, les Etudes I et II ont tout d'abord confirmé la présence de symptômes associés à des TMS du rachis lombaire tels que la présence de douleurs pendant la réalisation de l'activité de taille de la vigne. Les méthodes d'observation et d'analyse de l'activité utilisées dans ces deux études ont mis en évidence l'adoption, sur de longues périodes, de flexions et rotations du tronc qui exposent les vigneronnes et les vignerons à un risque important de TMS au niveau du rachis lombaire. Ces résultats, qui apportent un regard nouveau sur la façon dont ces personnes réalisent l'activité de taille, renforcent l'intérêt et la nécessité de concevoir, mettre en œuvre et d'évaluer une action spécifiquement dédiée à la prévention des TMS du rachis lombaire au sein de cette population.

De façon intéressante, le Château Larose-Trintaudon, employeur des vigneronnes et vignerons des Etudes I et II avaient déjà mis en place des actions de prévention des TMS de la région lombaire. Des solutions techniques, telles que l'utilisation de sièges de vigne avaient été proposées aux vigneronnes et vignerons. Ces solutions présentaient l'avantage d'offrir au personnel la possibilité de varier les positions de travail au cours de l'activité, notamment d'alterner les postures assises et debout. Cependant, le travail des sols par les tracteurs et la présence de sols argileux ont rendu l'utilisation de ces solutions impossibles. Une autre solution, en théorie prometteuse, consistait à augmenter la hauteur de la vigne. En effet, une étude de Kato et al (2006) a montré qu'en augmentant cette dernière, il était possible de réduire significativement le temps passé à tailler la vigne en adoptant des postures considérées comme « extrêmes » dans la littérature scientifique. Cette solution, bien qu'efficace, n'était pas envisageable au sein du Château Larose-Trintaudon en raison des normes et réglementations en vigueur en France. Par exemple, l'écartement entre les rangs de vigne ne peut excéder 1,8m et la hauteur de feuillage doit-être inférieure à 1,06m. Une autre piste pour la prévention des TMS du rachis lombaire jusqu'alors inenvisagée par le Château Larose-Trintaudon, mais déjà expérimentée dans d'autres secteurs d'activités tels que le secteur industriel ou le secteur hospitalier, consistait à mettre en place un programme d'activités physiques adaptées (APA) sur le lieu de travail. Cette piste de travail, qui semblait, au regard du contexte de l'entreprise, la plus appropriée, a fait l'objet de l'Etude III.

Dans ce contexte, l'Etude III de ce travail doctoral avait pour objectif de concevoir, mettre en place et d'évaluer un programme supervisé d'APA réalisé sur le lieu de travail. En ce sens, un programme conçu pour développer l'endurance des muscles extenseurs et fléchisseurs du tronc ainsi que la souplesse du rachis, capacités neuromusculaires amoindries par la présence de TMS du rachis lombaire, a été proposé à l'ensemble des 25 vigneronnes et vignerons du Château Larose-Trintaudon. Quinze d'entre eux se sont portés volontaires pour intégrer l'Etude III. Sur ces 15 personnes, 9 ont choisi d'intégrer un groupe dit 'intervention' et 7 un groupe dit 'contrôle'. Le groupe intervention a suivi un programme de 8 semaines organisé de la façon suivante. Tout d'abord, il était demandé aux vigneronnes et vignerons du groupe intervention de réaliser quotidiennement, sur leur temps de travail et sous la supervision d'un enseignant en APA un échauffement de 15 minutes. Cet échauffement avait pour objectif d'augmenter l'amplitude articulaire et de mobiliser l'ensemble des muscles et articulations particulièrement sollicités dans la journée de travail dans les vignes. Ensuite, les vigneronnes et vignerons ont été invités à suivre deux séances hebdomadaires supervisées de renforcement musculaire et d'étirements. Ces séances d'une durée de 60 minutes ont été réalisées hors temps de travail dans une salle, prévue à cet effet, mise spécialement à disposition par le Château Larose-Trintaudon. Enfin, les effets de ce programme d'APA sur l'endurance des muscles fléchisseurs et extenseurs du tronc, ainsi que sur la souplesse du rachis et de la sensibilité à la pression au niveau lombaire ont été évalués à quatre reprises, soit (1) avant de commencer le programme, (2) après quatre semaines, (3) à la fin du programme (c'est-à-dire après 8 semaines) et (4) quatre semaines après l'arrêt du programme. Les résultats de l'Etude III ont tout d'abord montré qu'avant de commencer ce programme, l'endurance des muscles extenseurs et fléchisseurs du tronc des deux groupes (contrôle et intervention) était particulièrement faible. A la fin du programme, les évaluations ont révélé que le groupe intervention avait amélioré de près de 70 secondes et de 142 secondes son endurance des muscles extenseurs et fléchisseurs du tronc. Il est important de constater que cette amélioration, qui dépasse largement celles observées dans des programmes similaires proposés dans d'autres secteurs d'activités, permet aux vigneronnes et vignerons d'atteindre des performances identiques, si ce n'est supérieures, à celles de personnes du même âge en bonne santé et qu'elle permet à plusieurs d'entre eux de dépasser des valeurs protectrices de survenue de TMS du rachis lombaire. Ces résultats positifs observés sur les capacités neuromusculaires des vigneronnes et vignerons sont également à mettre en relation avec la diminution significative de la sensibilité à la pression observée au niveau de la région lombaire. Cette diminution témoigne pour le groupe intervention des effets positifs du programme d'APA sur le système nociceptif et sur les mécanismes de la douleur. Enfin, un des résultats les plus prometteurs de l'Etude III est certainement le taux de présence de 100% observé au cours du programme. En d'autres termes, les vigneronnes et vignerons ont suivi l'intégralité des séances initialement planifiées. Pourquoi ce résultat est certainement le plus important ? Tout d'abord, plusieurs auteurs ont mis en évidence que l'efficacité du programme sur les capacités neuromusculaires des participants était conditionné par ce taux de participation. Plus les participants pratiquent et plus les effets sont importants. Autrement dit, l'amélioration significative des capacités neuromusculaires et la diminution de la sensibilité à la pression observés au cours de ce programme d'APA semblent intimement liées. Ensuite, un taux de présence élevé est un argument important pour convaincre les employeurs de continuer à financer ce type de programme.

Si les résultats présentés dans l'Etude III étaient prometteurs pour la prévention des TMS du rachis lombaire des vigneronnes et des vignerons, ils se devaient d'être confirmés et complétés par une étude complémentaire conduite sur une population plus importante d'une part, dans plusieurs entreprises vini-viticoles, d'autre part. Aussi l'Etude IV avait tout d'abord pour objectif de mesurer à plus grande échelle les effets du programme d'APA sur les capacités neuromusculaires présentées précédemment et la sensibilité à la pression de la région lombaire de vigneronnes et vignerons. Pour répondre au premier objectif, deux entreprises vini-viticoles (le Château Larose-Trintaudon et le Château Pichon Longueville Baron) ont proposé à leurs salariés de suivre le programme d'APA. Sur les deux entreprises, 29 personnes ont été volontaires pour participer à l'Etude IV dont 15 volontaires pour suivre le programme d'APA et ainsi constituer le groupe intervention. Les 14 autres vigneronnes et vignerons ont constitué le groupe contrôle. De façon similaire à l'Etude III, les résultats de l'Etude IV ont montré que le programme d'APA permettait d'augmenter l'endurance des muscles extenseurs et fléchisseurs du tronc, d'améliorer la souplesse du rachis et de diminuer la sensibilité à la pression de la région lombaire des vigneronnes et vignerons du groupe intervention. Le second objectif de l'Etude IV était d'identifier les facteurs susceptibles de favoriser ou de limiter l'efficacité du programme d'APA. Pour répondre à ce second objectif, une évaluation sommative des procédés, conduite sous la forme d'entretiens semi-structurés et de questionnaires, a été réalisée. L'Etude IV a tout d'abord montré que l'organisation autour du programme d'APA avait contribué à son efficacité. Par exemple, l'engagement répété des deux entreprises dans des démarches d'amélioration des conditions de travail a certainement permis aux salariés de ces dernières (de la direction générale aux vigneronnes et vignerons) d'être sensibilisés à ce type d'action et a ainsi contribué à faciliter la mise en place du programme d'APA. Ce résultat renforce l'idée selon laquelle une action de prévention de TMS ne peut être efficace que si elle s'intègre pleinement dans la politique de l'entreprise. L'évaluation des procédés a également démontré que les conditions de conception et de mise en œuvre du programme d'APA ont aussi contribué à son efficacité. En effet, les vigneronnes et vignerons du groupe intervention ont mentionné dans cette évaluation les qualités d'adaptation dont ont fait preuve les enseignants en APA. Capacités à adapter les exercices proposés, pendant les séances, aux douleurs, capacités et envies de chacun des salariés ont été mises en avant. La littérature scientifique a en effet démontré que lorsque l'enseignant en APA n'est pas en mesure de proposer de telles adaptations, les participants sont moins enclin à suivre les séances et abandonnent rapidement. Enfin, l'évaluation des procédés a mis en avant la capacité du programme d'APA à recréer du lien social dans les deux entreprises, levier indispensable à une prévention efficace des TMS. Dans leur ensemble, les résultats de L'Etude IV ont d'une part confirmé à plus grande échelle les résultats obtenus dans l'Etude III. Ils ont d'autre part mis en évidence que l'efficacité d'un programme d'APA dépend en particulier de la culture de l'entreprise en termes de santé au travail, des capacités de collaboration entre les différents acteurs (Direction générale, managers, vigneronnes et vignerons, enseignants en APA), des qualités d'écoute et d'adaptation des enseignants en APA.

Pour conclure, ce travail doctoral a démontré l'efficacité d'un programme supervisé d'APA dispensé sur le lieu de travail pour augmenter les capacités neuromusculaires et limiter l'aggravation des douleurs lombaires de salariés vigneronnes et vignerons. Plus largement, ce travail doctoral souligne la nécessité de questionner et d'analyser en amont les situations de travail afin de déterminer et d'adapter les actions à mettre en place. Même si ce travail présente des résultats encourageants et une méthode prometteuse pour la prévention des TMS du rachis lombaire des vigneronnes et vignerons, il se doit encore d'être poursuivi pour construire une action de prévention efficace et pérenne dans ce secteur. En effet, la durée du programme d'APA ne répond pas à un des enjeux majeurs de la prévention des TMS qui repose sur la mise en place de programmes plus longs et durables. Pour proposer ce type d'action, les activités réalisées tout au long de l'année, c'est-à-dire l'acanage, le pliage ou encore le sécaillage, se doivent d'être analysées. Ensuite, lorsque des résultats positifs sont reportés sur les capacités neuromusculaires et les mécanismes de douleur, il est fréquent d'observer, après plusieurs années, des effets sur l'absentéisme, le présentéisme ou encore la productivité. Aussi, des futures études devront-elles s'attacher à évaluer, à court, moyen et long termes, l'efficacité du programme d'APA sur ces variables. Il faut également garder à l'esprit que de tels programmes représentent un cout non négligeable pour les entreprises. En sens, il est indispensable dans les années à venir de démontrer que le programme d'APA présente un retour sur investissement suffisant pour que ces dernières soient définitivement convaincues de le reconduire chaque année. Enfin, ce travail doctoral présente l'activité physique adaptée sur le lieu de travail comme *une* solution adaptée au contexte des entreprises vini-viticoles. Cette solution n'est cependant ni unique, ni exclusive. Dans les années à venir, associée à une transformation des formes d'organisation, des formes de management et associée à des évolutions techniques et technologiques, cette solution se devra d'être intégrée dans une approche globale et efficace du problème des TMS.

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A Matthew, mon ami parti trop tôt… Still loving you Mat

List of papers

Paper 1: Balaguier R, Madeleine P, Hlavackova, P, Rose-Dulcina K, Diot B and Vuillerme N. Ergonomic evaluation of pruning activity among the Chateau Larose-Trintaudon vine-workers. Proceedings of the 11th International Symposium on Human Factors in Organisational Design & Management and the 46th Annual Nordic Ergonomics Society Conference (ODAM-NES 2014).IEA Press. 965-970, 2014.

Paper 2: Balaguier R, Madeleine P, Rose-Dulcina K, Vuillerme N. Trunk kinematics and low back pain during pruning among vineyard workers-A field study at the Chateau Larose-Trintaudon. PloS One. 2017;12(4):e0175126.

Paper 3: Balaguier R, Madeleine P, Rose-Dulcina K and Vuillerme N. Effects of a worksite supervised adapted physical activity program on trunk muscle endurance, flexibility and pain sensitivity among vineyard workers. J Agromedicine. 2017; 22(3):200-214.

Paper 4: Balaguier R, Madeleine P and Vuillerme N. Effectiveness and summative process evaluation of a worksite supervised intervention using adapted physical activity in viticulture: A non-randomized controlled trial.

List of abbreviations

ACSM:	American College of Sports Medicine
APA:	Adapted physical activity
GP:	General practitioner
LBP:	Low back pain
LTPA:	Leisure time physical activity
MSA:	Agricultural French mutual benefit society
NIOSH:	The National Institute for Occupational Safety and Health
OPA:	Occupational physical activity
PA:	Physical activity
PPT:	Pressure pain thresholds
RCT:	Randomized controlled trial
RR:	Relative risk
SA:	Sickness absence
SD:	Standard deviation
WHO:	World Health Organization
WMSD:	Work related musculoskeletal disorder
WPAP:	Workplace physical activity program

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INTRODUCTION

1. Agriculture, viticulture and prevalence of work related musculoskeletal disorders – the scale of the problem

The prevalence of work related musculoskletal disorders (WMSDs) is dramatically high in agriculture (Driscoll et al. 2014; Lee et al. 2014; McMillan et al. 2015; Osborne et al. 2012) and represents, in France, the first cause of occupational diseases (MSA: Agricultural Mutual Benefit Society, 2014). In this sector, statistics provided by the MSA show that numerous body regions such as the hand/arm system and the low back area are commonly affected by WMSDs. The MSA also reports that more than 800 000 working days are lost due to these conditions. Furthermore, the average number of WMSDs increases by approximately 1.6% each year. If a closer look at viticulture which employs nearly 600 000 people and provides more than 15% of the French agricultural output (Institut Français de la vigne et du vin, 2015 ; MSA: Agricultural Mutual Benefit Society, 2014) is taken, it is interesting to note that this sector is at the top of the agricultural sectors affected by WMSDs (MSA: Agricultural Mutual Benefit Society, 2014). Also, over a period of ten years, the cases of WMSDs have been multiplied by five (EU-OSHA, 2012). It is also now clearly established that musculoskeletal pain is widespread among vineyard workers. Indeed, in 2005 and among 1674 vineyard workers, the MSA reported respectively a 61.5% and a 31.1% prevalence of musculoskeletal pain of the low back and of the wrists over the twelve-month period. More recently, in a reference study (Bernard et al. 2011) conducted among nearby 4000 French vineyard workers, the prevalence of musculoskeletal pain among this population was 50%, 33% and 30% respectively over the back area, the upper extremity and the neck/shoulder region. When compared with other occupational settings (Figure 1), the prevalence of musculoskeletal pain over twelve months among vineyard workers is as high as among physiotherapists (Cromie, Robertson, and Best 2000), industrial workers (Widanarko et al. 2011) or healthcare workers (Davis and Kotowski 2015) for the low back, the wrists and the elbows. However, musculoskeletal pain over the neck and shoulders seems to be less widespread.

Altogether, these findings highlight the scale of the WMSD problem among the agriculture and viticulture work force. They also emphasize the high prevalence of these conditions over the low back area and the hand/arm system. It is noteworthy that this problem is expected to worsen since the world's population is aging and this phenomenon is associated with an increased risk of health problems (Bevan 2015; Woolf, Erwin, and March 2012).

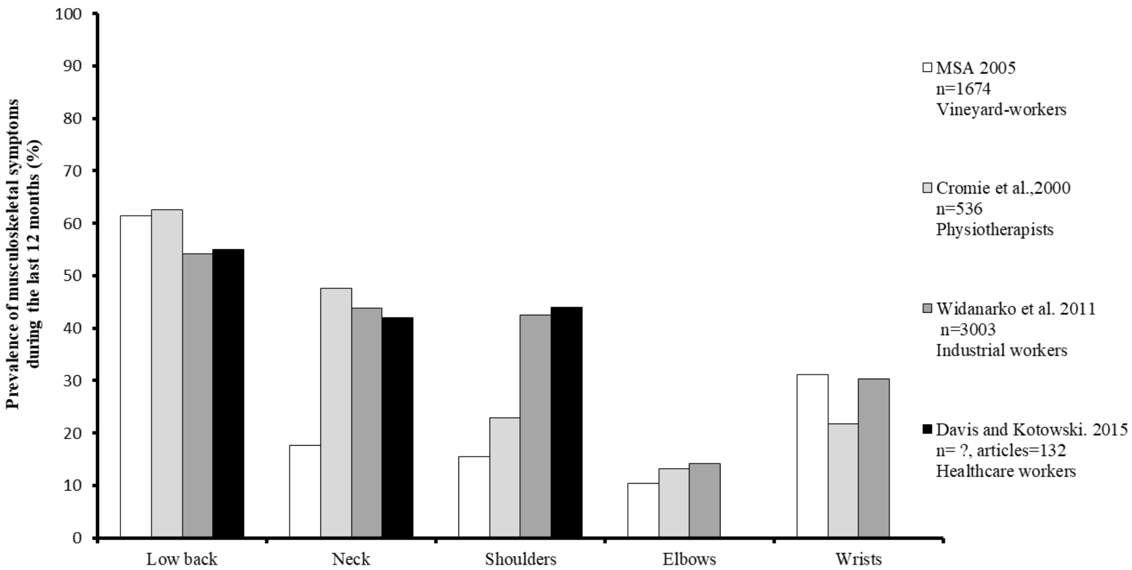

Figure 1. Prevalence of musculoskeletal pain during the last 12 months according to five body regions (low back, neck, shoulders, elbows and wrists) for four occupational settings (vineyard-workers, physiotherapists, industrial workers, healthcare workers). Figure created from data presented by MSA (2005), Cromie and colleagues (2000), Widanarko and colleagues (2011) and Davis and Kotowski (2015).

2. Why is it crucial to manage work related musculoskeletal disorders? – Application to the viticulture sector

Nowadays, it is now widely accepted that WMSD prejudice at the (i) individual, (ii) employer and (iii) societal levels (Berger et al., 2001 ; Black et al., 2008 ; Summers, Jinnett and Bevan, 2015, Woolf, 2012).

From the individual workers' perspective, WMSDs are responsible for pain, fatigue, reduction of work capacity, risk of career interruption resulting in a deterioration of their quality of life and well-being (Roux et al. 2005; Walker-Bone et al. 2004; Woolf and Pfleger 2003; Woolf, Erwin, and March 2012). For example, in viticulture, almost 73% of the vineyard workers reported pain over at least one anatomical location over the last 12 months (MSA, Rapport de l'enquête réalisée en France en 2005 auprès de viticulteurs exploitants et salariés. 2005). In the previous section, it was also mentioned that the low back region was the anatomical region the most affected by musculoskeletal pain with a 12 months prevalence of more than 50%.

From the employers' perspective, WMSDs are likely to decrease work productivity (de Vroome et al. 2015; Leijten et al. 2014; Zhang, McLeod, and Koehoorn 2016). Thus, De Vroom and colleagues (2015) among the Dutch population from 2007 to 2011 estimated that the production cost increase per day and per employee due to WMSDs was about 186 euros. Furthermore, the lost production time while the worker is still at work but experiencing WMSDs was estimated at 1.6 hours for an 8-hour working day (Lötters, Meerding, and Burdorf 2005). Musculoskeletal pain also leads to a degradation of the social climate, an increase in early retirement (Blekesaune and Solem 2005; Brenner and Ahern 2000;

Karpansalo et al. 2002; Westerlund et al. 2009) and absenteeism (Andersen et al. 2011; Woolf and Pfleger 2003; Zhang, McLeod, and Koehoorn 2016). For instance, Karpansalo and colleagues (2002) reported that WMSDs are responsible for almost 40% of the early retirement among Finnish workers. These authors further demonstrated that heavy physical work was associated with an increased risk of early retirement due to WMSDs (OR=2.21). It is interesting to note that WMSDs also lead to work reorganization with, for instance, an increased workload for the remaining workforce, the call to service providers, the recruitment and training of new workers (Berger et al. 2001).

Finally, from the societal perspective, it is interesting to note that in viticulture, a report from the MSA (MSA, Rapport de l'enquête réalisée en France en 2005 auprès de viticulteurs exploitants et salariés. 2005) showed that 62.3% of vineyard workers suffering from musculoskeletal pain have consulted a general practitioner due to this pain. Hence, among this population of workers, almost 88% have received a medical or a surgical treatment. Even if it is difficult to estimate the health care costs associated with WMSDs in viticulture, in the agriculture sector the latter reach almost 5 million euros per year. The increase in health care utilization is not the only societal burden associated with the high prevalence of WMSDs. Indeed, in France, when a worker is absent from work due to a WMSD, the health insurance organisation (i.e. the MSA in viticulture) has to pay the employee a compensation for the loss of wage. Of note, in viticulture, the amount of the workers' compensation due to WMSDs reaches approximately 40 million euros per year.

Through these examples further illustrated in Figure 2 and with regards to the high morbidity associated with WMSDs, it seems obvious that limiting the occurrence and aggravation of these conditions among vineyard-workers can be considered as a prerequisite for the health of the worker, the company and the society.

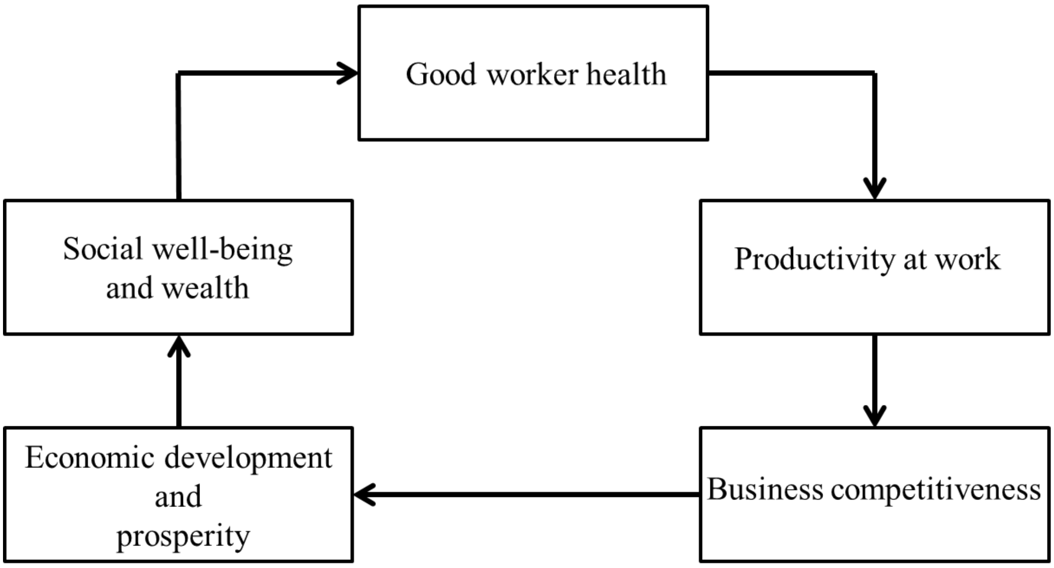

Figure 2. Relationship between worker health and company and society wealth. Adapted from Burton and colleagues (2010).

3. How to build an effective work-related musculoskeletal disorders prevention program in viticulture?

a) Understand the etiology of work related musculoskeletal disorders

Nowadays, the prevention of WMSDs in viticulture remains challenging (Macdonald and Oakman 2015; unnett 2014; Punnett and Wegman 2004; Roquelaure 2016; van der Beek et al. 2017; Wells 2009). One of the reasons put forward by the existing literature to explain that challenge is the complexity of the WMSDs' determinants, i.e. their multifactorial origin. Therefore, a better understanding of WMSDs' etiology is a key component for effective treatment and prevention of such conditions (Punnett et al. 2009; Punnett 2014; Wells 2009).

Interestingly, one of the first who identified risk factors of WMSDs was Bernardino Rammazzini during the XVIIth century (Ramazzini, 1700). In his book entitled "De morbis Artificum Diatriba", i.e. diseases of the workers; Ramazzini mainly revealed the presence of biomechanical risk factors such as awkward postures, prolonged stationary postures and repetitiveness. These risk factors have now been widely acknowledged and documented in the scientific literature (da Costa and Vieira 2010; Hoogendoorn et al. 2000; Hoogendoorn et al. 2002; Marras and Karwowski 2006; Punnett et al. 1991; Punnett and Wegman 2004). In viticulture, repetitiveness of the hand-arm system has already been clearly demonstrated (Roquelaure et al. 2001, 2002, 2004; Wakula et al. 1999). For instance, Wakula and colleagues (1999) highlighted that during the performance of pruning activity the average cutting rate was close to 30 cuts/minute, i.e. almost 14000 cuts extrapolated over a working day. Furthermore, Roquelaure and colleagues (2002) placed emphasis on the fact that cutting leads to the adoption of extreme wrist postures. Since the XVIIth century, three other main risk factors have been proposed namely (1) individual, (2) organizational and (3) psychosocial risk factors. Thus, individual risk factors commonly encompass age, body mass and gender. Of note, it is now clearly established that the occurrence of WMSD symptoms increases with age (Kinge et al. 2015; Widanarko et al. 2011; Woolf and Pfleger 2003) and that women are more likely to suffer from WMSDs than men (Côté 2012; Hoy et al. 2010; Kinge et al. 2015; Widanarko et al. 2011). Interestingly, and as in the United States of America (Lee et al. 2014; Osborne et al. 2012), the Netherlands or Sweden (Osborne et al. 2012), this phenomenon is also present in French viticulture (Bernard et al. 2011; MSA: Agricultural Mutual Benefit Society, 2014). In this sense, although employees aged from 40 to 60 years represent only 40% of the workforce in this sector, almost 70% of the WMSDs are declared among this age group. As illustrated in Figure 3 and Figure 4, this latter information makes the vineyard-workers aged between 40 and 60 years the age group the most affected by WMSDs (Bernard et al. 2011; MSA: Agricultural Mutual Benefit Society, 2014). Finally, while organizational factors increasing the risk of WMSDs include absence of job rotation (Simoneau et al. 1998), shift work (Punnett et al. 2009), rapid work pace (Simoneau et al. 1998), performance-based wages (Ajslev, Persson, and Andersen 2015) or inappropriate workstation and equipment design (Carayon, Smith, and Haims 1999), psycho-social risk factors commonly include low perception of co-workers and supervisor support (Macdonald and Oakman 2015; Punnett et al. 2009; Wells 2009), low perception of recognition (Macdonald and Oakman 2015), low decision latitude and high perception of quantity requirement (Oakman et al. 2017; Punnett et al. 2009). Even if the effects of most of these factors have not yet been addressed in viticulture, Bernard and colleagues (2011) reported that low job control and effort reward imbalance were the two main psycho-social risk factors strongly associated with musculoskeletal pain in this sector.

Interestingly, Carayon and colleagues (1999) suggested that these risk factors interact with each other. For instance, they reported that work organization necessarily influences the strength of the biomechanical and psychosocial risk factors. Thus, imposing work pace will automatically determine the exposure time to repetitive motions, forces or postures. To illustrate this complex relationship between organizational, biomechanical and psychosocial risk factors, Ajslev and colleagues (2015) have recently compared the effects of two wage systems (i.e. a performance-based wage and a time-based wage system) on physical exertion and time pressure among 456 construction workers. They found that in comparison with the workers on a time-based wage, workers on the performance-based wage reported higher perceived levels of physical exertion and time pressure. In the same vein, Bao and colleagues (2016) reported that another organizational factor, in this case job rotation, could influence biomechanical and psychosocial risk factors. Indeed, they first showed that workers with job rotation were more likely to report low job satisfaction. Secondly, using observational methods (i.e. video recordings), they highlighted higher exposure to biomechanical risk factors such as forceful and repetitive motions among workers with job rotation.

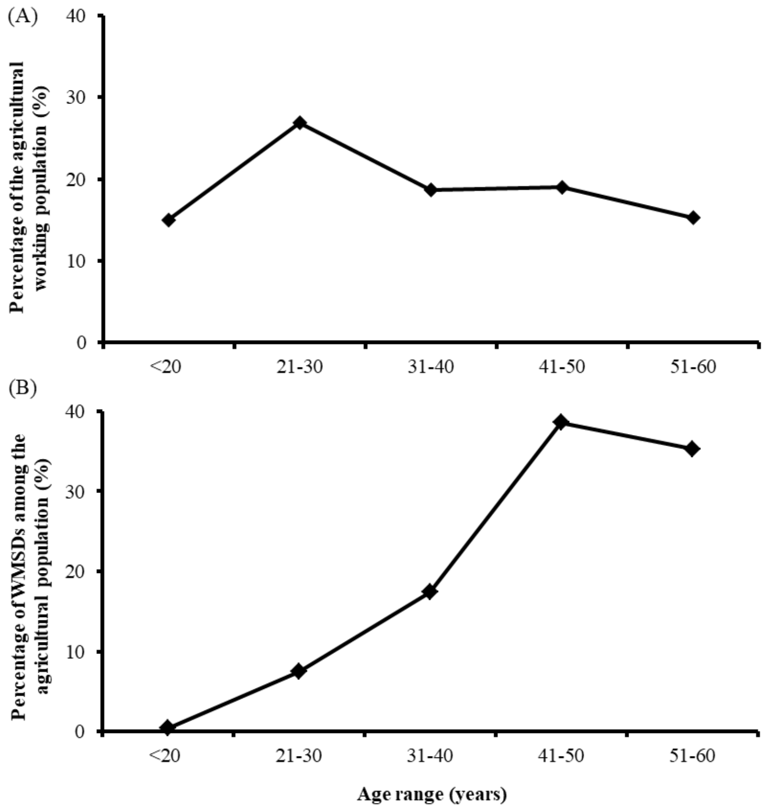

Figure 3. Relationship between the percentage of agricultural working population (A) and the percentage of WMSDs among this population (B) according to different age-range. Figure created from data presented in “Observatoire des troubles musculo-squelettiques des actifs agricoles. Bilan national 2009-2013”.MSA: Agricultural Mutual Benefit Society (2014).

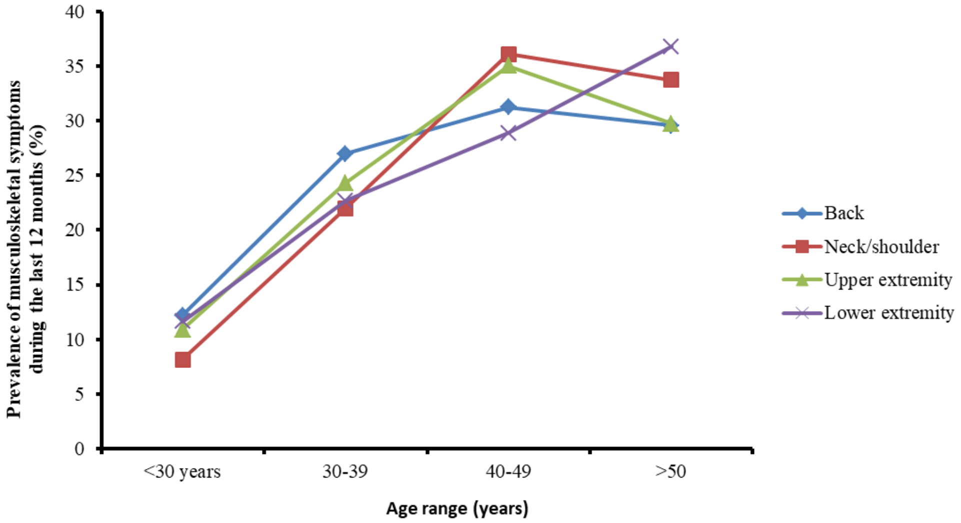

Figure 4. Prevalence of musculoskeletal pain among vineyard-workers reporting pain during the last 12 months according to four body regions (back, neck/shoulders, upper extremity and lower extremity) and to different age range. Adapted from "Observatoire des troubles musculo-squelettiques des actifs agricoles. Bilan national 2009-2013". MSA: Agricultural Mutual Benefit Society, 2014.

b) Develop an intervention

For a better understanding of the complex relationship between all the risk factors, numerous authors have proposed a causation model of WMSDs (Bao et al. 2016; Carayon, Smith, and Haims 1999; Karsh 2006; Macdonald and Oakman 2015; Oakman, Rothmore, and Tappin 2016; Roquelaure 2016) including both individual, biomechanical, psychosocial and organizational risk factors. In one of these models, presented in Figure 5 and adapted from Roquelaure (2016), the environment in which the company evolves is likely to affect its work organization, itself liable to modify the exposure to biomechanical and psychosocial risk factors. Finally, this exposure may, depending on the bio-psycho-social characteristics and resources of the individual, lead to the occurrence of WMSDs.

Therefore, this model raises three fundamental points for the development of effective and sustainable WMSD prevention programs. First, the implementation of such solutions is necessarily conditioned by a prior analysis of the context and the work organization (Bao et al. 2016; Carayon, Smith, and Haims 1999; Coutarel, Aptel et Roquelaure, 2008; Goetzel et al. 2007; Macdonald and Oakman 2015; Oakman et al. 2018; Roquelaure 2016; Simoneau et al. 1998; van der Beek et al. 2017). Secondly, as risk factors interact with each other, the modification of one of them is likely to have repercussion at different hierarchical levels, i.e. from the front-line workers to the top managers. Therefore, the implementation of WMSD prevention programs requires at least a high collaboration between workplace participants as well as, preventers, social partners and insurers (Oakman et al. 2018; Roquelaure 2016; van der Beek et al. 2017). Thirdly, it is noteworthy that the exposure to a risk factor does not automatically mean occurrence of WMSDs. On the one hand, the effects of a risk factor on workers' health depend on its bio-psycho-social characteristics and resources (Holtermann et al. 2010; Roquelaure, 2016; Simoneau et al. 1998). On the other hand, the effects also depend on the degree of exposure which is the product of three main characteristics, i.e. intensity, frequency and duration of exposure (Simoneau et al. 1998). Thus, identifying WMSD risk factors and quantifying the risk exposure is crucial to prioritize and further adapt WMSD prevention programs (Punnett 2014; van der Beek et al. 2017).

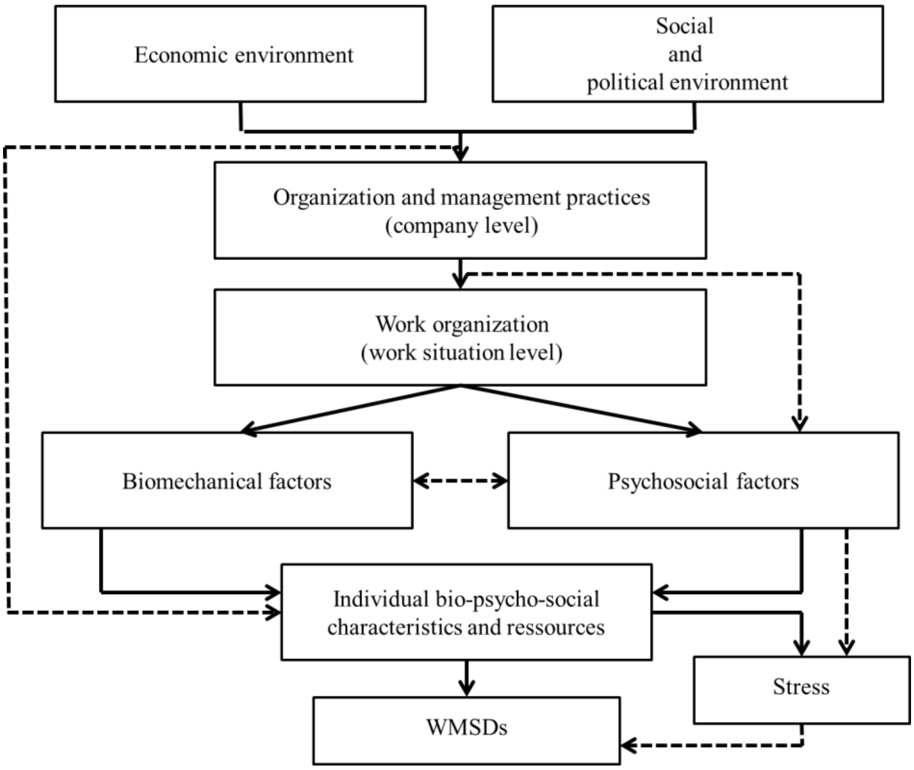

Figure 5. Conceptual model of work related musculoskeletal disorders. Adapted from Roquelaure (2016).

c) Evaluate the intervention

Finally, the evaluation of the intervention is crucial to appreciate the consistency between results and objectives, i.e. to appreciate the effectiveness of the intervention (Coutarel et al. 2009; Goetzel et al. 2014). Interestingly, as the effects of a WMSDs prevention program may be differed on time, short and long-term effects are expected (Holtermann et al. 2010; Karsh 2006). On the one hand, Holtermann and colleagues (2010) associated short-term effects with an improvement of individual resources or a reduction of the work demand. On the other hand, they associated expected long-term effects with a reduction of absence for sick leave, increased work ability, improved social climate or reduction in health care use. However, assessing long-term effects emphasizes the importance of having a sufficient anteriority in the prevention program, i.e. at least two years (Chapman and American Journal of Health Promotion Inc 2005; Goetzel and Ozminkowski 2008; Goetzel et al. 2014). Moreover, this latter finding confirms that the WMSD programs must be fully integrated in the workplace and therefore highlights the need to identify which contextual factors may explain the success or failure of these programs. In this sense, an increasing body of literature put forward evidence for the association of an effectiveness evaluation with a process evaluation (Linan et al. 2002; Saunders, Evans, and Joshi 2005; van der Beek et al. 2017; Wierenga et al. 2013). Such process evaluation gives a deeper insight on barriers and facilitators in relation with the characteristics of the organization, the WMSD programs, the implementer and the participants

(Wierenga et al. 2013). Therefore, pairing an effectiveness evaluation with a process evaluation is fundamental (1) to better understand the efficacy of the WMSD program and (2) to provide recommendations to optimize the implementation and integration of future interventions as a long-term WMSD prevention strategy (Linan et al. 2002; Saunders, Evans, and Joshi 2005; van der Beek et al. 2017; Wierenga et al. 2013).

d) Promotion of physical activity among workers, a promising strategy to handle work-related musculoskeletal disorders?

Occupational versus leisure-time physical activity

Interestingly, a relationship exists between the level of physical activity and the socioeconomic position (Beenackers et al. 2012; Schneider and Becker 2005). On the one hand, the lowest socioeconomic position including manual workers such as vineyard-workers are those with the highest level of occupational physical activity (Beenackers et al. 2012; Mäkinen et al. 2010) and the highest risk of WMSDs. On the other hand, this population is also the one presenting the lowest level of leisure time physical activity (Kirk and Rhodes 2011; Mäkinen et al. 2010; Schneider and Becker 2005). Within this context, the scientific literature has paid particular attention to assess the effects of the level of leisure time and occupation physical activity on WMSDs. In this sense, numerous studies documented the positive effects of leisure time physical activity on workers' health (Ratzlaff, Gillies, and Koehoorn 2007; Shiri and Falah-Hassani 2017), well-being (Kaleta et al. 2006) or work ability (Arvidson et al. 2013; Calatayud et al. 2015). As an example of these health enhancing effects, in a recent meta-analysis of six prospective studies, Shiri and Falah-Hassani (2017) reported that the risk of LBP was decreased by 11% to 16% among participants being physically active during leisure time compared with participants with no regular physical activity. Besides the effects on mortality, Holtermann and colleagues (2012) showed that being physically active during leisure time limited the risk of absence for sick leave. However, as illustrated in Figure 6, these authors reported that this risk was significantly increased with higher level of occupational physical activity.

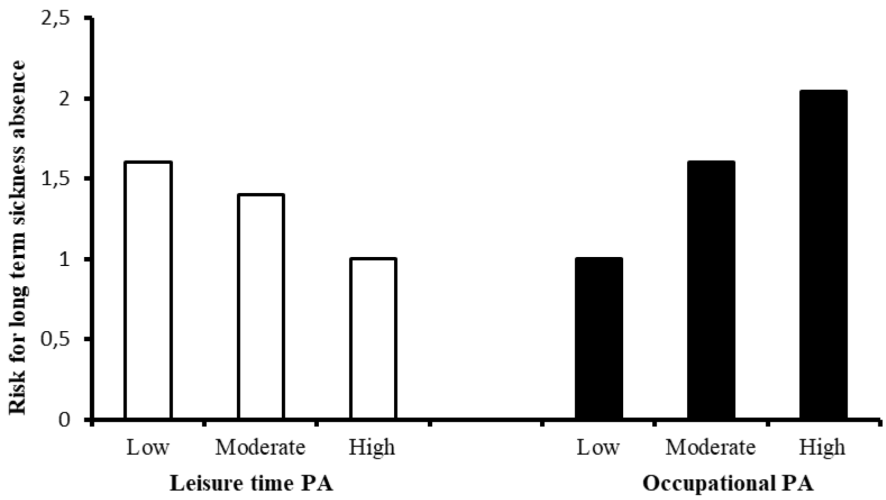

Figure 6. Levels of leisure time and occupational physical activity and risk of long term sick leave. Adapted from Holtermann and colleagues (2012).

Although not yet completely understood, the origin of the contrasting effects of these two different physical activities on workers' health may stem from different mechanisms (Holtermann et al. 2017; Søgaard and Sjøgaard 2017). For instance, while leisure time physical activity is generally performed at the workers' own discretion, the performance of occupational physical activity is determined by employers. Furthermore, leisure time physical activity is commonly performed with appropriate intensity and duration to improve workers' health and also allows sufficient recovery time between sessions that subsequently limit fatigue and musculoskeletal pain. On the other hand, occupational physical activity is commonly performed with insufficient and/or inappropriate intensity, duration and recovery time (Holtermann et al. 2017) to provide positive effects on workers' health.

Altogether, these findings illustrated the significance of the promotion of leisure time physical activity especially among workers exposed to high levels of occupational physical activity (Stenholm et al. 2012) such as agricultural workers. Indeed, in addition to presenting high levels of occupational physical activity, this population is also one of the occupational settings presenting the lowest level of leisure time physical activity (Gu et al. 2016). To go further, as illustrated in Figure 7, targeting among this population workers aged over 40 years seems particularly relevant since this age group experiences the highest level of WMSD prevalence (see Figure 4), the strongest function decline but, above all, present one of the lowest participation rates in LTPA, i.e. 27%.

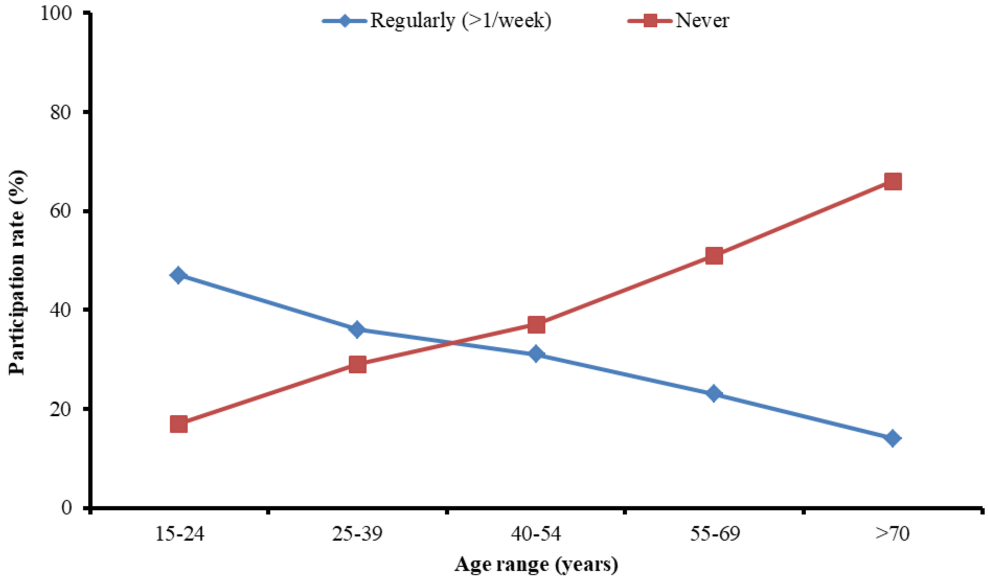

Figure 7. Percentage of respondents of the European Union reporting performing sports or physical activity more than once per week (blue line) and those reporting no engagement (red line) according to the age range. Data adapted from "Commission Européenne. Eurobaromètre 2009 : Sport et activités physiques. Eurobaromètre spécial 334. 2010".

Implementation of workplace physical activity programs (WPAP), effectiveness and challenges

For the last two decades, the idea of implementing physical activity programs at the workplace has gained interest and the worksite is now considered as a key setting to promote a healthier lifestyle (Goetzel and Ozminkowski 2008; Kuoppala, Lamminpää, and Husman 2008; Quintiliani et al. 2007) such as to promote leisure time physical activity. One major reason for this is that workplaces offer the possibility to reach and to raise awareness of a large number of workers and particularly those at risk of developing WMSDs (Kuoppala, Lamminpää, and Husman 2008; Quintiliani et al. 2007). The World Health Organization further suggests that the working environment should offer all workers the opportunity to make healthy choices in order to reduce their exposure to risk. In this sense, recent reviews and meta-analyses have assessed the effectiveness of WPAPs on musculoskeletal pain (Bell and Burnett 2009; Coury, Moreira, and Dias 2009; Moreira-Silva et al. 2016; Proper et al. 2003; Van Eerd et al. 2016), general health (Conn et al. 2009), physical fitness (Proper et al. 2003), absenteeism (Conn et al. 2009; Oesch et al. 2010; Pedersen and Saltin 2015; Rongen et al. 2013; Schaafsma et al. 2010; White et al. 2016), work productivity and financial outcomes (Kuoppala, Lamminpää, and Husman 2008; Pereira et al. 2015; Proper et al. 2008; Rongen et al. 2013; White et al. 2016).

Regarding musculoskeletal pain, results of these reviews tend in the same direction (Coury, Moreira, and Dias 2009; Moreira-Silva et al. 2016; Proper et al. 2003; Sjøgaard et al. 2016; Van Eerd et al. 2016), i.e. a moderate to strong evidence for musculoskeletal pain reduction. First, Proper and colleagues (2003) conducted a critical review of WPAP (from 1980 to 2000) to increase the level of physical activity found strong evidence that physical activity performed at the workplace can reduce pain over the low back. Another recent meta-analysis by Moreira-Silva and colleagues (2016) supported these conclusions. Indeed, a moderate evidence for a reduction in neck/shoulder pain and LBP was reported based on 12 RCT studies performed from 1990 to 2013. To go further, the systematic review by Coury and colleagues (2009) investigating the influence of the type of work (i.e. sedentary or physical) on pain concluded on the basis of 6 low quality RCT studies to a moderate evidence of the effectiveness of WPAP to reduce LBP among workers performing physical work. To our knowledge, since 2016 and the last meta-analysis by Moreira-Silva and colleagues (2016), no review has specifically addressed the effects of WPAP on musculoskeletal pain. However, an overview of results from 15 RCT mostly performed after 2010 and embedding PA at the workplace has demonstrated a strong evidence of the effectiveness of such programs on pain reduction (Sjøgaard et al. 2016). For instance, among a wide range of occupational settings such as office-workers, cleaners, industrial workers, laboratory technicians and health-care workers, Sjogaard and colleagues (2016) reported that WPAPs were able to significantly decrease pain intensity from 2 to 3 points on a 10 points NRS. At this point, however, for other outcomes such as absences for sick leave and work productivity, conclusions remain uncertain. Indeed, while in their review of literature, Proper and colleagues (2008) and Pereira and colleagues (2015) reported non-significant effect of WPAP on absences for sick leave, Conn and colleagues (2009) and more recently White and colleagues (2016) have concluded for consistent evidence for the effectiveness of WPAP on this outcome particularly for sick leave associated with LBP. In the same synthesis of systematic reviews, White and colleagues (2016) have also pointed out the contrasting effects of WPAP on work productivity and financial outcomes. This latter finding was supported in the review by Pereira and colleagues (2015) on eight RCT published from 2000 and 2015.

Interestingly, challenges associated with the implementation of WPAP may explain that no study has yet questioned the effects of WPAP in viticulture. The first challenge concerns the study design. Indeed, even if RCT are considered to be the gold standard to assess the effectiveness of a program, in the workplace context, this study design is called into questions by numerous authors due to its difficult implementation (Burton, Organization, and others 2010; Kwak et al. 2006; Marshall 2004; Punnett 2014; Schelvis et al. 2015; Shephard 1996, 1999; West et al. 2008). For instance, employers are generally reluctant to randomization because of the risk for their company not to be included in the intervention group and because randomization commonly involves a delay to follow the intervention for half of the workers, i.e. the control group (Burton, Organization, and others 2010; Kwak et al. 2006). Even when a control group exists, the workplace is likely to favor exchanges or contacts between participants increasing the risk of bias (Punnett 2014; Schelvis et al. 2015; Shephard 1996, 1999). A second challenge is linked to the difficulty to recruit a large number of employees within the company. Indeed, the participation rate which is defined by Waters and colleagues (2011) as the number of consenting participants divided by the number of potential or eligible participants is too rarely reported in WPAP studies. Hence, with 49% WPAP participation rate is one of the lowest rates compared with other types of physical activity interventions (Kwak et al. 2006; Robroek et al. 2009; Waters et al. 2011). The third challenge concerns the characteristics of the participants. This latter is well described in a study by MacVinen and colleagues (2015). After four months of WPAP aiming at increasing the level of PA among university workers, MacVinen and colleagues (2015) observed that the number of participants reaching the targeted level of PA did not change from baseline to follow-up. These authors argued that the high initial level of PA of the participants had limited the possible effects of the WPAP. This result also reported by others (Burton, Organization, and others 2010; Kilpatrick et al. 2015; Marshall 2004; Pereira et al. 2015; Proper et al. 2003; Rongen et al. 2013; Shephard 1996, 1999) suggests that WPAP tend to recruit fit, healthy, physically active and motivated participants. However, as mentioned above, workers at higher risk of WMSDs of the low back are generally those who are not physically active enough during leisure time, unfit, with little interest in PA and little awareness about the beneficial effects of PA. Fourthly, concluding for the ineffectiveness of WPAP involves questioning whether the program was received in the intended dose, i.e. to question the compliance rate. In their review of literature on the effects of WPAP on work productivity, Pereira and colleagues (2015) concluded that (1) not enough studies reported this rate and that (2) when mentioned the compliance rate was relatively low, i.e. about 50%. To go further, even if the scientific literature agree for moderate to strong evidence regarding the positive effects of WPAP on pain and health outcomes (Coury, Moreira, and Dias 2009; Moreira-Silva et al. 2016; Proper et al. 2003; Sjøgaard et al. 2016), numerous authors have reported that the compliance rate is also a key component of WPAP effectiveness on these outcomes. In other words, a dose-response relationship exists between the magnitude of changes and the compliance rate, i.e. the higher the compliance rate, the greater effectiveness (Jakobsen et al. 2016; Jay et al. 2015; Linton, Hellsing, and Bergström 1996; Nikander et al. 2006; Sjøgaard et al. 2016).

On the one hand, these findings lend support to the implementation of WPAP as a promising strategy to reduce WMSDs symptoms among workers. On the other hand, these findings also question the characteristics of the most effective WPAP and highlight the necessity to evaluate their effectiveness. These two points are introduced in the following sections.

Best practice studies –Arguments for workplace adapted physical activity programs

In a recent review including eight studies assessing the effectiveness of WPAP in controlling WMSDs, Coury and colleagues (2009) as well as Van Eerd and colleagues (2016) have provided relevant conclusions for future studies and clinical practice. To sum up, studies with WPAP (1) lasting more than 10 weeks and (2) implementing "heavy" resistance exercises, i.e. exercises with dumbbells and elastic bands, seem effective in pain reduction. Similar conclusions were found among 1093 workers suffering from CLBP by Schaafsma and colleagues (2011). These conclusions are also in line with the ACSM guidelines recommending the implementation of resistance training including dynamic exercises performed two to three times per week with a duration of 20 to 60 minutes to improve muscular fitness (Garber et al. 2011) and with recent guidelines provided by Booth and colleagues (2017) for the implementation of resistance training programs among participants with chronic musculoskeletal pain. To go further, regular supervised training sessions seem necessary for the WPAP effectiveness. For instance, in their review Coury and colleagues (2009) reported a strong evidence of ineffectiveness for unsupervised WPAP. In the same vein, Rongen and colleagues (2013) reported that the WPAP effectiveness was multiplied by four when supervised. The role of supervision is undeniably associated with the possibility to adapt the intervention to the participants' levels, needs, expectations and preferences also more observed in successful WPAP (Pereira et al. 2015). More recently, among 15 RCT studies reported high effectiveness of WPAP on workers' health and musculoskeletal pain, Sjogaard and colleagues (2016) confirmed that supervision was a key component of the effectiveness of WPAP and argued in favor of instructors specialized in sports science and health. Finally, the most effective and promising results for the prevention of WMSDs have been certainly reported by a research group over 10 years (Søgaard and Sjøgaard 2017). Indeed, this research group has reported positive effects of worksite adapted physical activity programs at short and long term on workers' health, well-being, sick leave and absenteeism. Interestingly, this research group adapted the program to the workplace (in terms of frequency and duration), to the workers (adaptation to its physical capacities, pain, needs) and finally to the work task. The summary of these general guidelines to the implementation of a worksite APA program is presented in Table 1.

Duration	At least 10 weeks
Frequency	2-3 times per week
Time	20-60 minutes
Type	Resistance training Dynamic exercises
Material	Dumbells Elastic band Free-weight
Supervision	Regular Specialist in sports science and health
Adaptation	To the workplace To the worker To the work task

Table 1. Summary of the general guidelines to implement effective workplace APA program.

THESIS AIMS

The main aim of this PhD thesis was to conduct effective actions that could prevent WMSD symptoms of the low back among vineyard-workers.

To reach this general objective, this PhD thesis was structured in two complementary sections consisting in a field ergonomic work exposure analysis (Part I) and the design, implementation and evaluation of a workplace APA program (Part II).

In Part I, two complementary studies were carried out (Study I and Study II).
The aim of Study I was threefold : (1) to collect self-reported musculoskeletal pain ratings among vineyard-workers during a working week of pruning activity, (2) to assess the effects of this working week on musculoskeletal pain and (3) using video-recordings to identify work related risk factors that may play a role in the occurrence of musculoskeletal pain among this population.
The aim of Study II was twofold: (1) to monitor during pruning activity and among vineyard-workers the duration of trunk forward bending and trunk rotation and (2) to investigate whether and to what extent the duration of trunk forward bending or trunk rotation is associated with perceived pain intensity and pressure pain sensitivity over the low back.

In Part II, two intervention studies were carried out (Study III and Study IV).
The aim of Study III was to design, implement and evaluate the effectiveness of a worksite supervised APA program among vineyard-workers.
The aim of Study IV was twofold :(1) to implement and evaluate on a broader scale the effectiveness of this APA program and (2) to perform a summative process evaluation to identify factors that may have affected the level of effectiveness of the APA program.

The framework of this PhD thesis is presented in details in Figure 8.

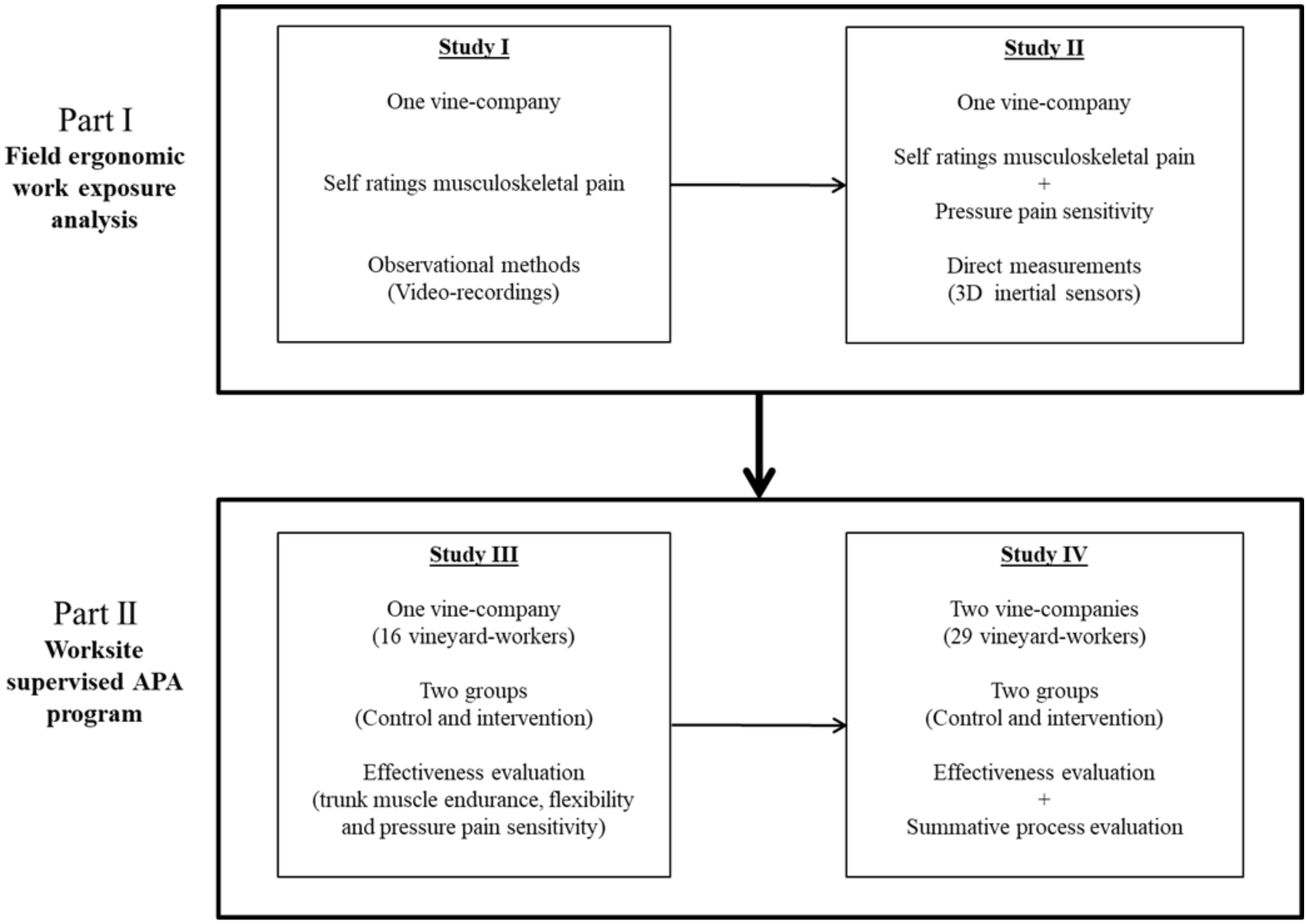

Figure 8. Experimental studies conducted during the PhD thesis. The arrows show relation between studies and between the two parts of the PhD thesis.

METHODS

This chapter described the main methodological aspects respectively for the ergonomic work exposure analysis and the worksite supervised APA program.

1. Field ergonomic work exposure analysis

Table 2 presents an overview of the characteristics of Study I and Study II, i.e. the experimental design, the physical exposure assessment methods, the exposure variables and the outcomes measured.

		Study I (n=11)	Study II (n=15)
Study type	**Cross-sectional**	X	X
Physical exposure assessment methods	**Observational methods**	X	
	Direct measurements		X
Exposure variables	**Duration of trunk forward bending**	X	X
	• Trunk thigh angle	X	
	• Flexion <30°,>30°,>60°,>90°		X
	Duration of trunk rotation		X
	• Rotation<10°,>10°,>30°		X
Outcomes measures	**Overall self-reported musculoskeletal pain intensity**	X	
	• Pain drawings/body map	X	
	Self-reported low back pain intensity	X	X
	Pressure pain threshold over the low back		X
	Relationship between trunk forward bending, trunk rotation, LBP intensity and pressure pain sensitivity		X

Table 2. Overview of Study III and Study IV.

a) Participants

For both Study I and Study II, all the vineyard-workers of the Château Larose-Trintaudon were invited to participate. Over the 25 vineyard-workers employed in this wine-producing company, 11 and 15 of them were volunteer workers to participate respectively in Study I and Study II. Characteristics of the participants are presented thereafter in Table 3.

	Study I	Study II
Sex	5 women 6 men	6 women 9 men
Age (years)	45.4 (6.3)	45.9 (5.9)
Height (cm)	166.6 (6.1)	167.5 (5.9)
Body mass (kg)	72.2 (12.4)	73.6 (14.1)
BMI (kg/m²)	25.9 (3.2)	26.1 (3.6)
Vineyard experience (years)	18.7 (6.6)	19.1 (5.8)
Pain over the low back during the last 12 months (number of vineyard-workers)	9	11

Table 3. Characteristics of the participants in Study I and Study II. Data are expressed as mean (standard deviation). BMI = body mass index.

b) Physical exposure assessment methods

Observational methods

In Study I, vineyard-workers were video-recorded once during pruning by a single observer placed perpendicularly to the vine row. Three anatomical markers were fixed on the vineyard-workers' shoulder, pelvis and knee to estimate trunk-thigh angle postures. Each video-recording was analyzed twice by the two examiners using the KINOVEA software (http://www.kinovea.org/) to quantify the time spent in the 10 following trunk-thigh angle intervals, i.e. inferior to 90°, [91°-100°], [99°-110°], [111°-120°], [121°-130°], [131°-140°], [141°-150°], [151°-160°], [161°-170°] and [171°-180°].

Direct measurements

In Study II, the duration of trunk forward bending and trunk rotation was obtained using one inertial measurement unit combining a tri-axial accelerometer, a tri-axial gyroscope and a tri-axial magnetometer allowing continuous posture angle measurement (I4 motion, Technoconcept, Mane, France; sampling frequency: 100 Hz). Because of the location of the pruning shears batteries this latter was fixed on the vineyard-workers' chest at the level of the sternum (Afshari et al. 2014). Reference measurements were performed prior the performance of pruning with the vineyard workers in an upright neutral standing position and looking straight forward for 1 minute. Thus, error due to the attachment of the sensor with an adjustable elastic belt could be eliminated (Raffler et al. 2017). Data were collected during 12 minutes of pruning activity and then analyzed using the I4 motion software.

c) Exposure variables

Duration of trunk forward bending

As in numerous other studies, the duration of trunk forward bending was chosen to quantify WMSD risk exposure (Freitag et al. 2007; Kazmierczak et al. 2005; Labaj et al. 2016; Schall, Fethke, and Chen 2016; Villumsen et al. 2015; Wong, Lee, and Yeung 2009).

In Study I, trunk-thigh angle was measured using three anatomical markers fixed on the vineyard-workers' shoulder, pelvis and knees.

In Study II and as shown in Figure 9, the percentage of time spent with the trunk bent forward was calculated using three cut-off angles, i.e. 30°, 60° and 90° (Villumsen et al. 2015; Wong, Lee, and Yeung 2009).

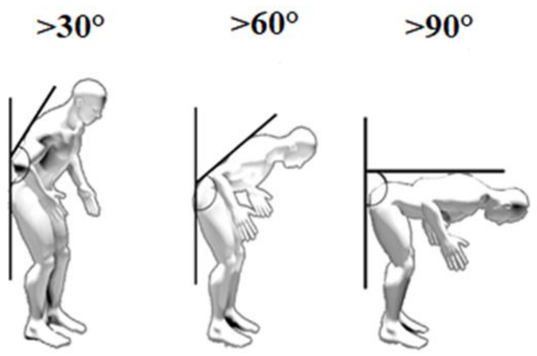

Figure 9. Representation of the three cut-off angles used to categorize the duration of trunk forward bending.

Duration of trunk rotation

In Study II and as shown in Figure 10, the percentage of time spent with the trunk rotated was calculated using two cut-off angles, i.e. 10°, 30° (Raffler et al. 2017; Teschke et al. 2009).

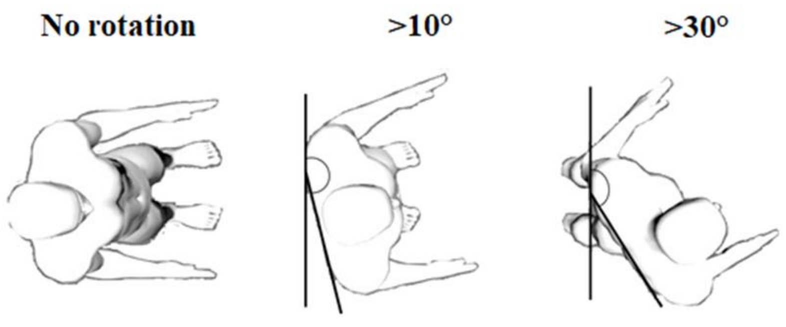

Figure 10. Representation of the three cut-off angles used to categorize the duration of trunk rotation.

d) Outcomes measures

Self-reported musculoskeletal pain

In Study I, vineyard-workers were asked to report the intensity of their pain over 22 anatomical locations using both a pain drawing (Figure 11) and a 0-10 numeric pain rating scale (no pain: score of 0; worst imaginable pain: score of 10). They were asked to fill in the pain drawing form twice a day, i.e. before and at the end of the working day over an entire working week of pruning activity, i.e. from Monday to Friday. This pain drawing form is a modified version of the Standardized Nordic Questionnaire (Kuorinka et al. 1987).

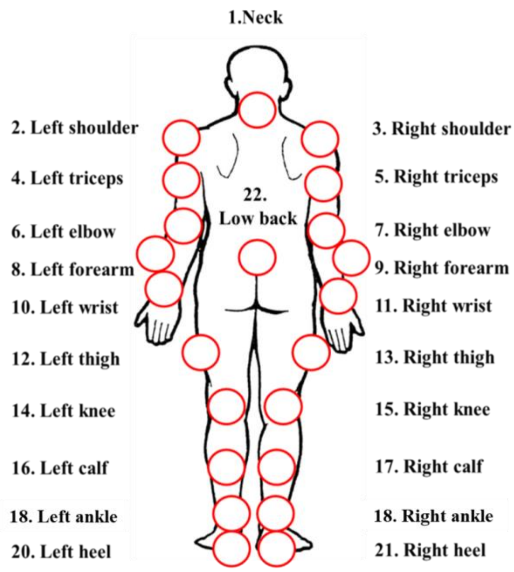

Figure 11. Pain drawing form with the 22 anatomical locations used in Study I.

In Study II, only low back pain intensity was reported using a 0-10 points numeric pain rating scale every day over a working week of pruning activity.The validity, reliability and sensitivity to change of a numeric pain rating scale have been demonstrated among numerous populations and this tool is considered as “a gold-standard” to assess pain (Chapman et al. 2011; Hawker et al. 2011).

Pressure pain threshold

Using an electronic pressure algometer (Somedic Algometer type 2, Sollentuna, Sweden), PPT were assessed over 14 anatomical locations over the low back area (Balaguier, Madeleine, and Vuillerme 2016a, 2016b). Pressure was applied increasingly at a constant rate of 30kPa/sec and vineyard-workers were asked to press a stop-button when the feeling of pressure changed to pain. Three trials were performed on each location and the mean of these trials was used for data analysis. The excellent reliability of this protocol has been recently reported among vineyard-workers (Balaguier, Madeleine, and Vuillerme 2016b). Excellent reliability of pressure algometry has also been reported by numerous authors among several populations (Balaguier, Madeleine, and Vuillerme 2016a; Koo, Guo, and Brown 2013; Paungmali et al. 2012)

e) Statistical analyses

In Study I, a three-way ANOVA with Period (before and after the working day), Days (from Monday to Friday) and Anatomical Location (22 anatomical locations, see Figure 11) as independent categorical variables was conducted for self-reported musculoskeletal pain. Post-hoc analyses allowing correction for multiple comparisons were performed whenever a significant main effect was reported in the three-way ANOVA. A significant alpha level was set at 5%. A one-way ANOVA with trunk-thigh cut-off angles (from inferior to 90° to 171-180°) as independent categorical variables was conducted for the duration of trunk forward bending.

In Study II, the comparison of time spent in different cut-off angles (i.e. <30°, >30°, >60°, >90° for trunk forward bending and <10°, >10° and >30° for trunk rotation) was performed using Mann-Whitney U-test. A significant alpha level was set at 5%. To further question the relationship between the duration of trunk bending, trunk rotation and LBP intensity or pain sensitivity, a Spearman rank coefficient correlation and a sensitivity analysis using a median split were used.

2. Workplace supervised adapted physical activity program

Table 4 presents an overview of the characteristics of Study III and Study IV, i.e. the experimental design and the outcomes measured.

		Study III (n=16)	**Study IV (n=29)**
Study type	**Cross-sectional**	X	X
	Non randomized	X	X
Groups	**Control group**	X	X
	Intervention group	X	X
Effectiveness evaluation	**Sit and reach**	X	X
	Finger to floor	X	X
	Right side bending	X	
	Left side bending	X	
	Trunk extensor endurance	X	X
	Trunk flexor endurance	X	X
	Pressure pain threshold	X	X
Summative process evaluation	**Context of the intervention**		X
	Dose delivered		X
	Dose received		X
	Fidelity		X
	Satisfaction of the participants		X

Table 4. Overview of Study III and Study IV.

a) Participants

Both in Study III and Study IV a non-randomized controlled design was chosen in concertation between all stakeholders. For this reason, vineyard-workers who volunteered to follow the worksite supervised APA program were included in the intervention group while the remaining volunteers were allocated into the control group. Flowcharts of participants' recruitment for both Study III and Study IV are presented in Figure 12 and Figure 13. Then, characteristics of the participants for both studies are presented in Table 5.

	Study I (n=16)		Study II (n=29)	
	Control group	**Intervention group**	**Control group**	**Intervention group**
Sex	1 women 6 men	5 women 4 men	7 women 7 men	6 women 9 men
Age (years)	44.7 (6.7)	45.7 (8.0)	43.0 (11.8)	39.9 (9.4)
Height (cm)	165.8 (5.9)	171.4 (7.6)	168.8 (9.1)	167.3 (8.5)
Body mass (kg)	72.0 (13.2)	78.8 (14.5)	84.7 (17.3)	72.3 (14.7)
BMI (kg/m²)	29.7 (4.5)	25.8 (4.9)	29.7 (4.9)	25.8 (4.5)
Vineyard experience (years)	18.3 (7.6)	19.3 (6.0)	21.4 (10.3)	15.6 (9.1)
Pain over the low back during the last 12 months (number of vineyard-workers)	4	9	9	11

Table 5. Characteristics of the participants in Study I and Study II according to groups (control or intervention). Data are expressed as mean (standard deviation). BMI = body mass index.

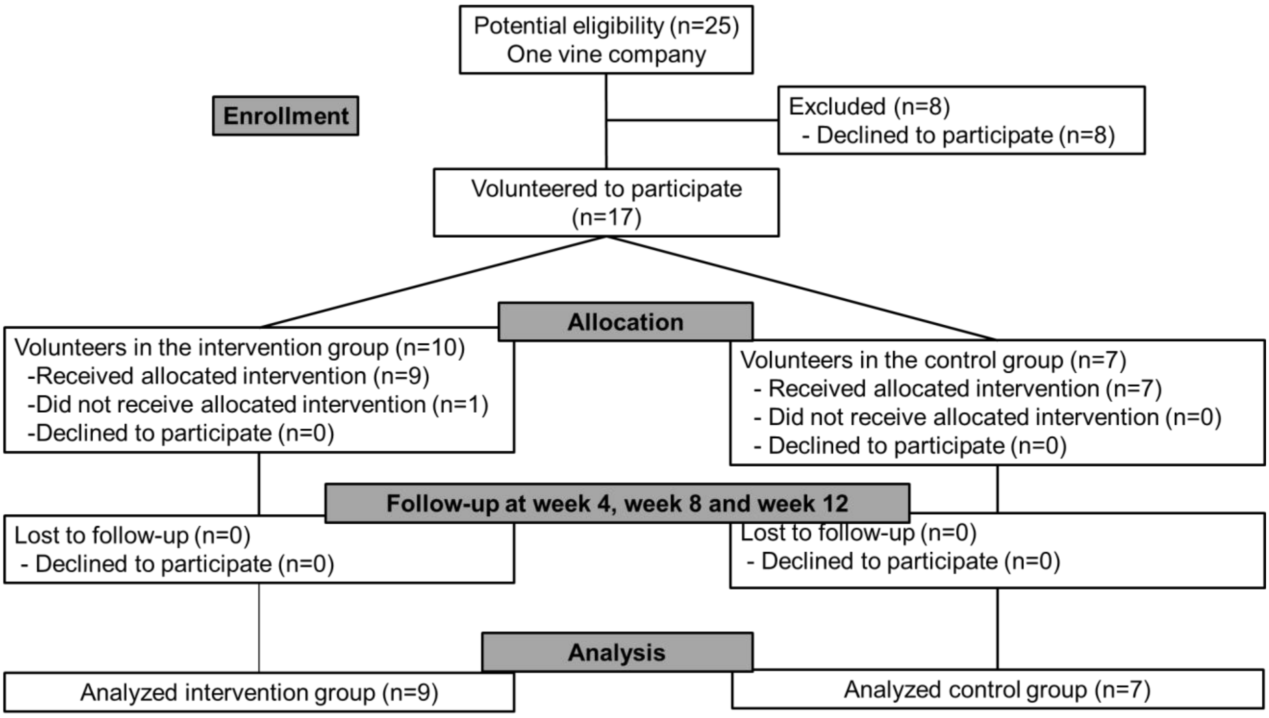

Figure 12. Flowchart of participants' recruitment in Study III

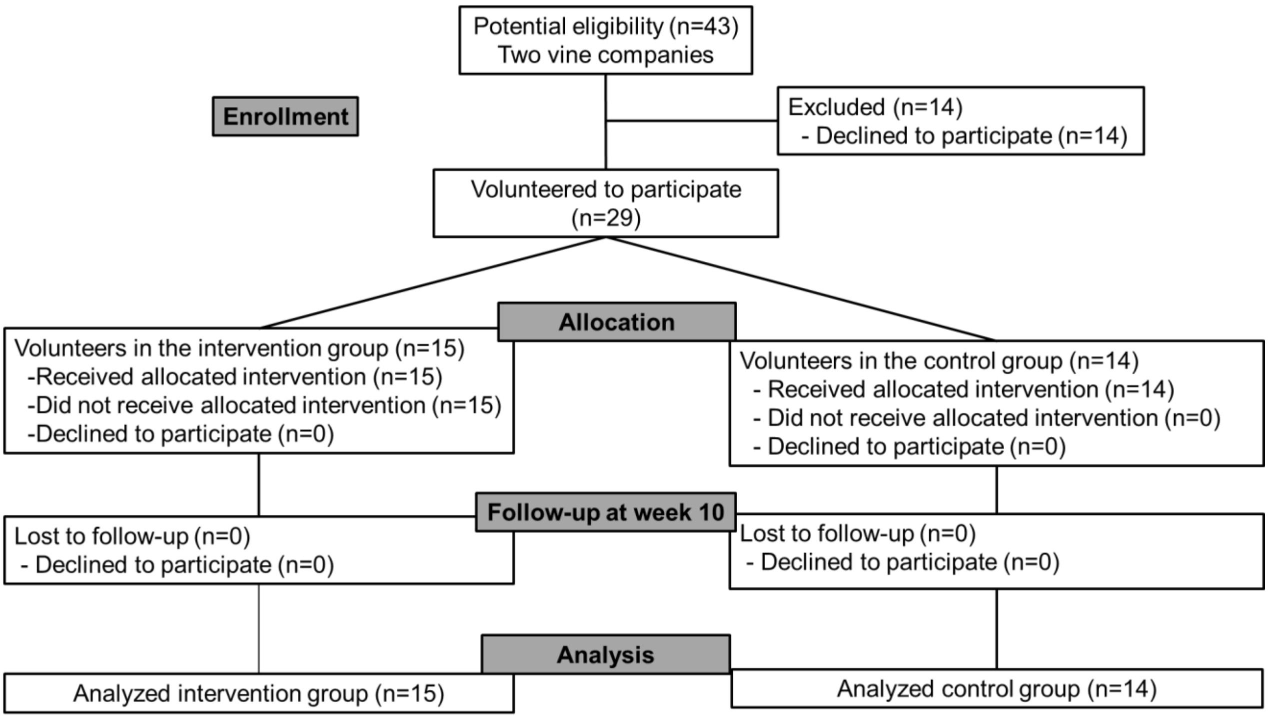

Figure 13. Flowchart of participants' recruitment in Study IV.

b) Workplace APA program

Warm-up

At the beginning of each working day, vineyard-workers were asked to perform a supervised warm-up included general and specific exercises. Both exercises designed to activate key muscles and joints particularly stressed during the working day involved static and dynamic movements. The aim of this warm-up was to improve range of motion in joints and elevate bodily and muscular temperature. The total duration of warm-up was fixed at 15 minutes (Racinais, Cocking, and Périard 2017). To get the most out of the warm-up, vineyard-workers were asked to start their daily activities within 15 minutes following the end of the warm-up (Racinais, Cocking, and Périard 2017).

APA training sessions

Vineyard-workers performed supervised strength and flexibility exercises twice per week in APA training sessions lasting one hour each. These sessions were offered during leisure time. Strength exercises were performed using materials such free-weights, kettlebells, elastic bands, medicine balls or swiss-balls. These exercises are regularly implemented in worksite supervised APA programs (Dalager et al. 2015; Jakobsen et al. 2016). APA instructors were in charge of the supervision of the APA training sessions. They were in charge of progressively increasing training intensity and exercise repetitions. They were also asked to ensure the correct exercise techniques and to adapt the exercises to the participants' characteristics (i.e. pain, physical capacities) when needed.

c) Effectiveness evaluation

Sit and reach

In a sitting position with the legs fully extended, vineyard-workers' feet were placed flat against a standardized box. They then reached forward as far as possible. The 0 point was set at 23cm from the vineyard-workers' feet (Lohne-Seiler et al. 2016). The best trial, i.e. the greatest distance between the 0-point and the arrival point of the sliding device was recorded for data analysis (Peacock et al. 2015). Excellent reliability has been previously reported for this test (Bozic et al. 2010). Sit and reach scores are correlated with hamstring flexibility ($r=0.67$) (Mayorga-Vega, Merino-Marban, and Viciana 2014).

Finger to floor

Standing on a 43 cm high box with the legs fully extended, vineyard-workers were asked to bend forward as far as possible. The distance from the tip of the middle finger to the floor was recorded in cm (Gauvin, Riddle, and Rothstein 1990). Of note, the 0-point was set at floor level. Vineyard-workers were asked to perform three trials and the best performance, i.e. the lowest distance between the middle finger and the floor was used for data analysis (Peacock et al. 2015). Perret and colleagues (2001) reported excellent validity and reliability for this test and concluded that this latter could be used in intervention study to measure spine stiffness.

Trunk side bending

To assess trunk lateral flexibility, vineyard-workers standing in a 43cm high box with the legs fully extended and the arm straight alongside the trunk were asked to tilt their trunk as far down as possible. The 0-point was set at floor level and the examiner measured the distance between the tip of the middle finger and the floor. Vineyard-workers performed three trials and the best performance was used for data analysis. This test is commonly performed among participants with musculoskeletal pain (Adams, Mannion, and Dolan 1999; Frost et al. 1982; Sadler et al. 2017) and its reliability is excellent (Frost et al. 1982).

Trunk muscle extensor endurance

To assess trunk muscle extensor endurance, vineyard-workers were lying flat on an examination table with the inguinal region set at the edge of the table, the trunk unsupported and the arms crossed on the chest (Banos et al. 2015; Demoulin et al. 2006; McGill, Childs, and Liebenson 1999). The test started when the vineyard-workers reached a horizontal position and finished after 240 seconds or when the vineyard-worker was no longer able to maintain this horizontal position (Banos et al. 2015; Demoulin et al. 2006). Satisfactory reliability and good validity have been reported among healthy and LBP participants (Demoulin et al. 2006).

Trunk flexor endurance

To assess trunk muscle flexor endurance, vineyard-workers were asked to fold their arms across the chest, to position their back against a wedge inclined at 70° and to flex their knees and hips at 90°. Then, vineyard-workers removed their back from the wedge and held this position for a maximum duration of 300 seconds (Banos et al. 2015; McGill, Childs, and Liebenson 1999). Good reliability and validity has been reported for this test by Denteneer and colleagues (2017).

d) Summative process evaluation

A mixed method framework, i.e. semi-structured interview and questionnaires, was used in the summative process evaluation. This mixed method approach questioned the six following components of the worksite supervised APA program; (1) the context of the intervention, (2) the dosed delivered, (3) the dose received, (4) the fidelity, (5) the satisfaction of the participants and (6) their suggestions for the implementation of future APA programs (Andersen and Zebis 2014; Saunders, Evans, and Joshi 2005; Wierenga et al. 2013).

e) Statistical analyses

For both Study III and Study IV, an intention to treat analysis was performed (Hollis and Campbell 1999; White et al. 2011). Therefore, missing values either at the beginning, at the end of the workplace APA program or at follow-up sessions were replaced by data obtained from the previous or following evaluation sessions (Gram et al. 2012). To determine whether the workplace supervised APA program had an effect on outcomes, a RM-ANOVA was performed. Groups (control and intervention) and sessions (weeks 0, 4, 8 and 12 in Study III and weeks 0 and 10 in Study IV) were used as independent categorical variables of the RM-ANOVA. In post-hoc analyses, Holm-Sidak test was used to estimate significant differences between groups and sessions.

RESULTS

1. Field ergonomic work exposure analysis

a) Study I

Self-reported musculoskeletal pain intensities and low back pain

In Study I, the self-reported pain intensity revealed that during a working week of pruning activity the low back was the most painful anatomical region followed by the right wrist and the right elbow. Then, results of the post-hoc tests performed in Study I further revealed for the low back region and five working days that the self-reported musculoskeletal pain ratings were significantly higher at the end of the working day compared with the start of the working day (2.2 ± 1.4 *versus* 3.6 ± 2.2, $P<0.0001$).

Duration of trunk forward bending using video recordings

In Study I, the use of video-recording showed that during 12 minutes of pruning the vineyard-workers spent more of their time with a trunk-thigh angle comprised in three intervals, i.e. (1) between 91° and 100°, (2) between 101° and 110° and (3) between 111° and 120° than in the other trunk-thigh intervals. Hence, results of descriptive statistics revealed that during the 12 minutes of pruning activity vineyard-workers did not spent time with trunk-thigh angle greater than 150° and that 79% of the 12 minutes was spent with a trunk-thigh angle of less than 120°.

b) Study II

Duration of trunk forward bending and trunk rotation using tri-axial embedded sensors

In Study II, results showed that during 12 minutes of pruning vineyard workers spent 58%, 21% and 3% of their time respectively with the trunk bent forward greater than 30°, 60° and 90°. Further, results of Mann-Whitney U-test revealed that vineyard-workers spent significantly less time with the trunk bent forward less than 30° than with the trunk bent forward more than 30° (Figure 14).

Then, results showed that vineyard-workers spent approximately 50% of the 12 minutes of pruning adopting trunk rotations both lesser and greater than 10°. Results of Study II also showed that vineyard-workers spent significantly more of their working time with the trunk rotated to the left side compared to the right side for trunk rotation cut-off angles <10° or >10°.

Relationship between the duration of trunk forward bending, trunk rotation, low back pain intensity and pressure pain sensitivity.

Spearman rank coefficient did not show any significant relationship between the duration of trunk forward bending and both self-rated musculoskeletal pain intensity over the low back (coefficient ranged between -0.2717 and 0.2717, p-values ranged from 0.3078 to 0.3273) or pressure pain sensitivity (coefficient ranged between -0.1464 and 0.1464, p-values ranged from 0.5756 to 0.6024). An absence of relationship was also reported between the duration of trunk rotation, LBP intensity and pressure pain sensitivity.

Then, when the duration of trunk forward bending was combined with the duration of trunk rotation, no relationship was reported between these two outcomes and both self-rated musculoskeletal pain intensity or pressure pain sensitivity.

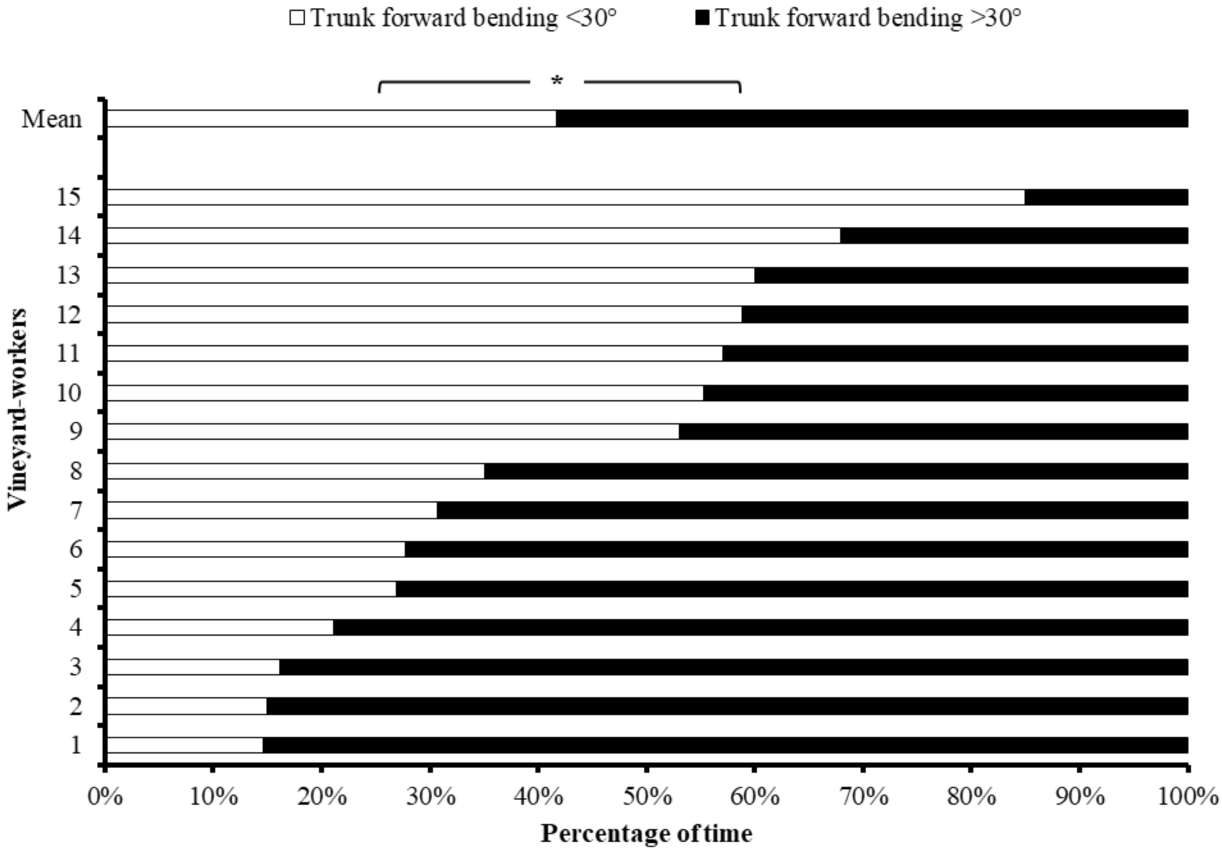

Figure 14. Percentage of time spent with the trunk bent forward <30° and >30° for each vineyard workers. *P < .05.

2. Workplace supervised adapted physical activity program

a) Effectiveness evaluation

Results of Study III and Study IV are presented in this section. At baseline and for both studies, no significant difference was observed between the intervention and the control group for all the outcomes except for the pressure pain sensitivity. This difference showed that the control group reported higher PPT than the intervention group. For both studies, results of the intention to treat analysis showed that changes observed from baseline to the end of the program were significantly larger among the intervention group than among the control group for all the outcomes, except for the sit-and-reach and the left side bending tests in Study III. These differences are presented in the Figure 15 to 19 for all the outcomes.

b) Summative process evaluation

Results of the summative process evaluation performed in Study IV showed that the APA program was delivered as planned, i.e. all warm-ups and APA training sessions were delivered by the APA instructors and followed by the vineyard-workers of the intervention group. The number of participants per session never exceeded 7 and the duration of the sessions was always respected. The process evaluation also revealed that satisfaction with the APA program was high among the participants. Thus, on a 5-point Likert scale (from strongly disagree to strongly agree), 15 vineyard-workers reported to agree or strongly agree that APA training sessions were adapted to their physical capacities, that the frequency of sessions was adapted and that the APA instructors were attentive to their special requests. All the vineyard-workers also declared that their opinion was sufficiently taken into account to design the APA program and that the latter allowed them to establish links with their colleagues. The summative process evaluation also showed that all the vineyard-workers felt that the APA program improved their well-being, their working conditions and decreased their low back pain intensity.

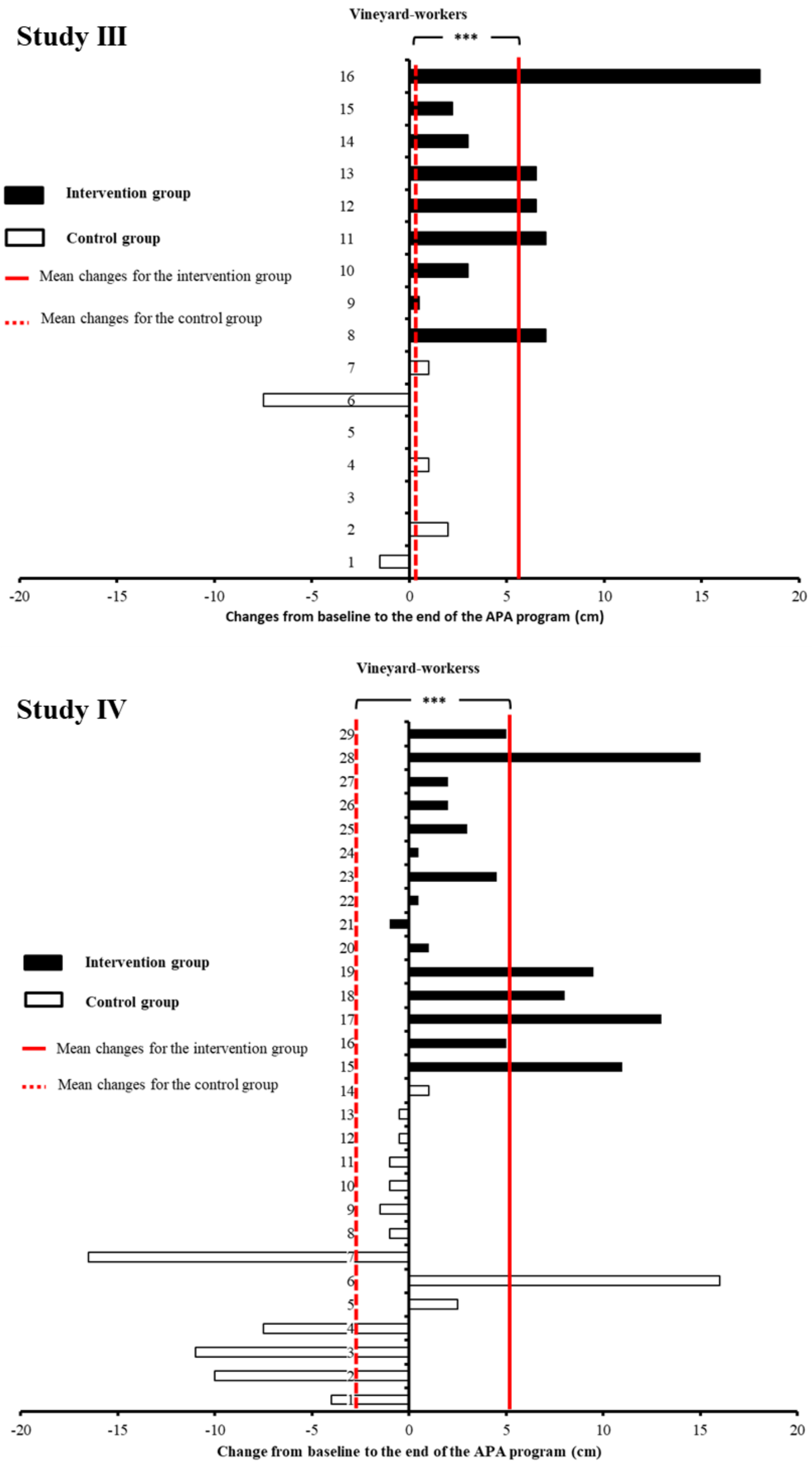

Figure 15. Changes from baseline to the end of the program for both studies (Study III: at the top ; Study IV: at the bottom), each vineyard-worker of the control group (white bar) and intervention group (black bar) for the finger to floor test. Mean changes for the control group are represented by the dotted red line while mean changes for the intervention group are represented by the continuous red line. *P < .05; **P < .01; ***P < .001.

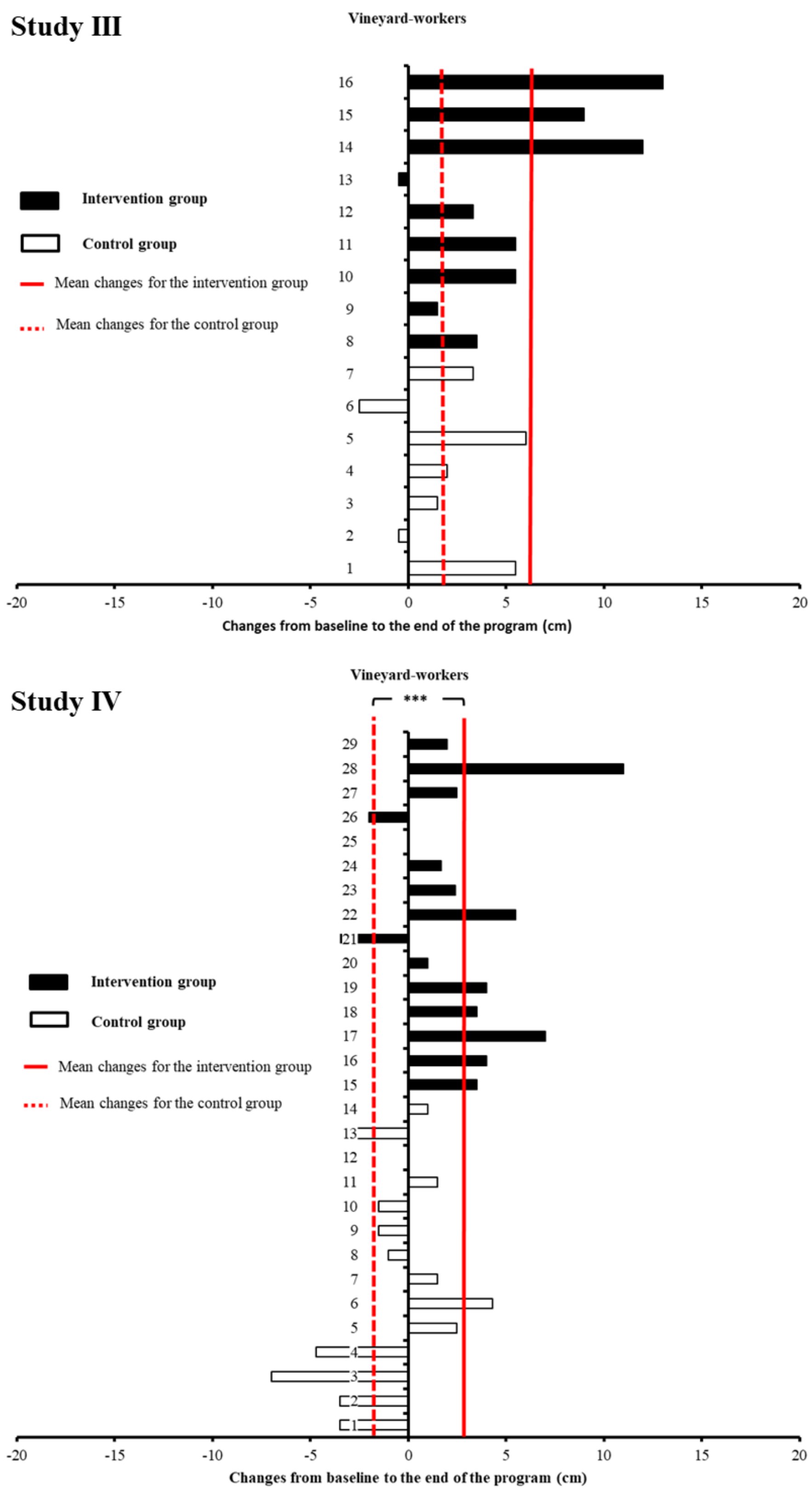

Figure 16. Changes from baseline to the end of the program for both studies (Study III: at the top; Study IV: at the bottom), each vineyard-worker of the control group (white bar) and intervention group (black bar) for the sit-and-reach. Mean changes for the control group are represented by the dotted red line while mean changes for the intervention group are represented by the continuous red line. *P < .05; **P < .01; ***P < .001.

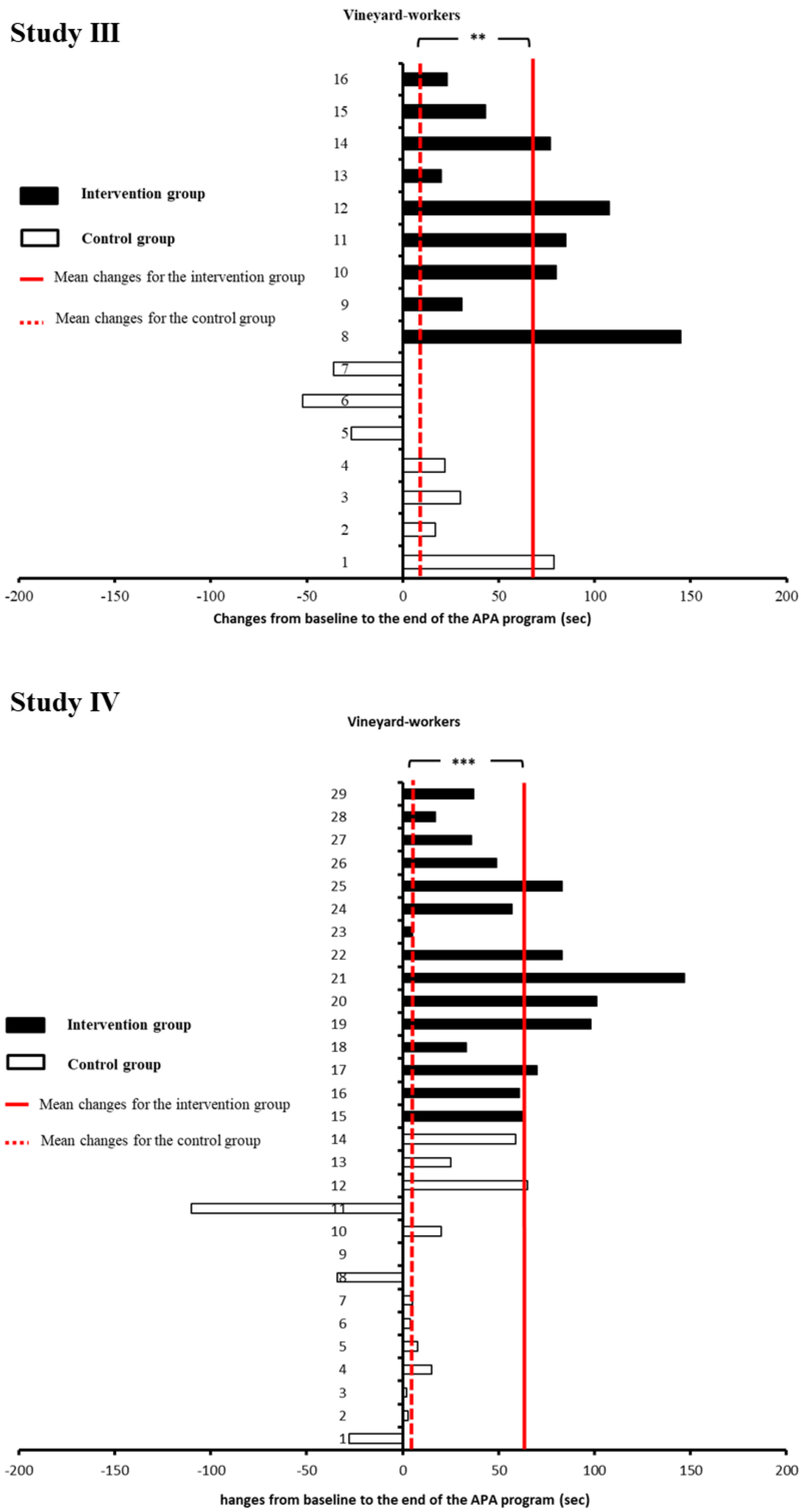

Figure 17. Changes from baseline to the end of the program for both studies (Study III: at the top ; Study IV: at the bottom), each vineyard-worker of the control group (white bar) and intervention group (black bar) for the trunk extensor endurance test. Mean changes for the control group are represented by the dotted red line while mean changes for the intervention group are represented by the continuous red line. *P < .05; **P < .01; ***P < .001.

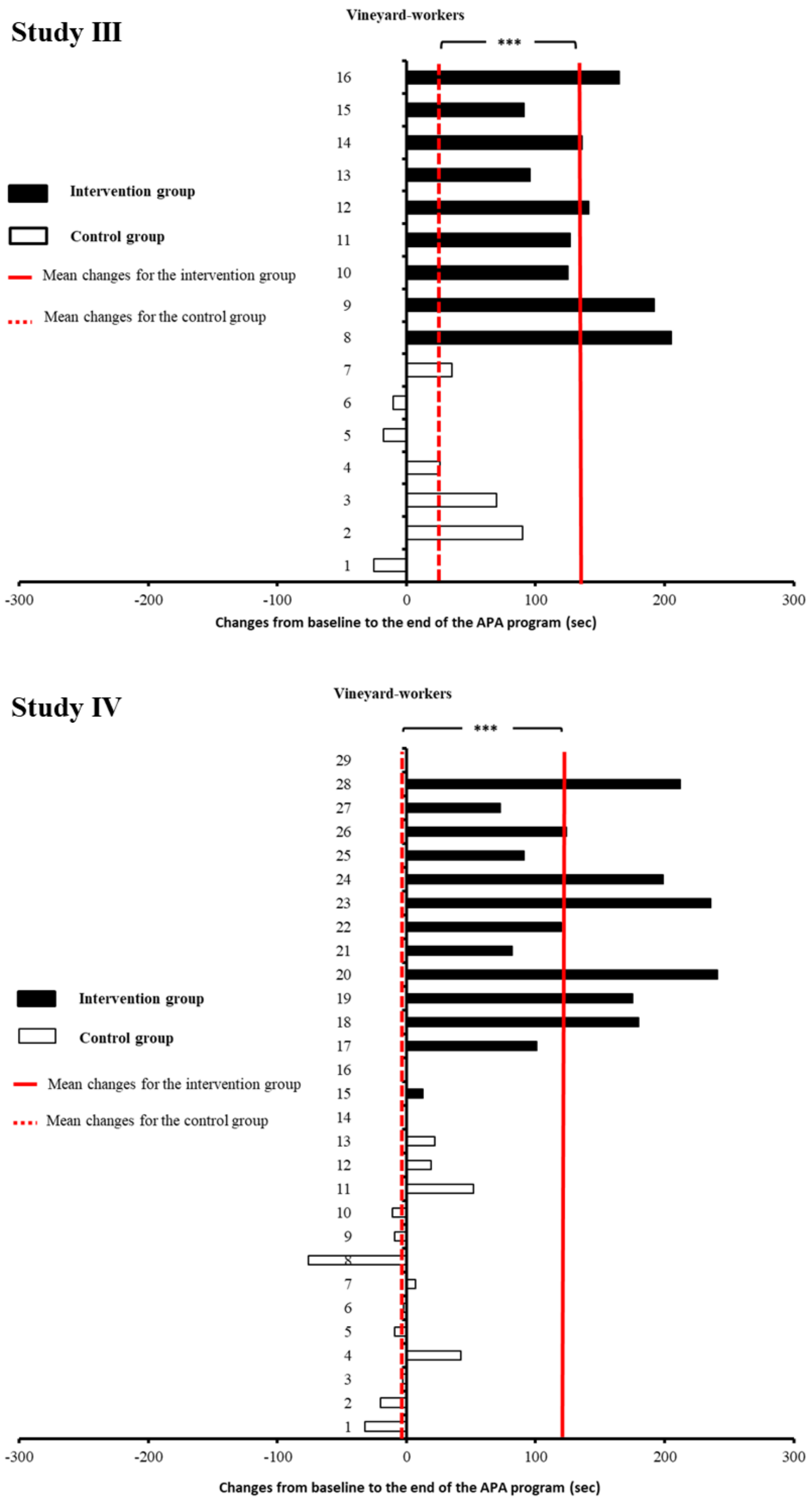

Figure 18. Changes from baseline to the end of the program for both studies (Study III : at the top ; Study IV: at the bottom), each vineyard-worker of the control group (white bar) and intervention group (black bar) for the trunk flexor endurance test. Mean changes for the control group are represented by the dotted red line while mean changes for the intervention group are represented by the continuous red line. *P < .05; **P < .01.

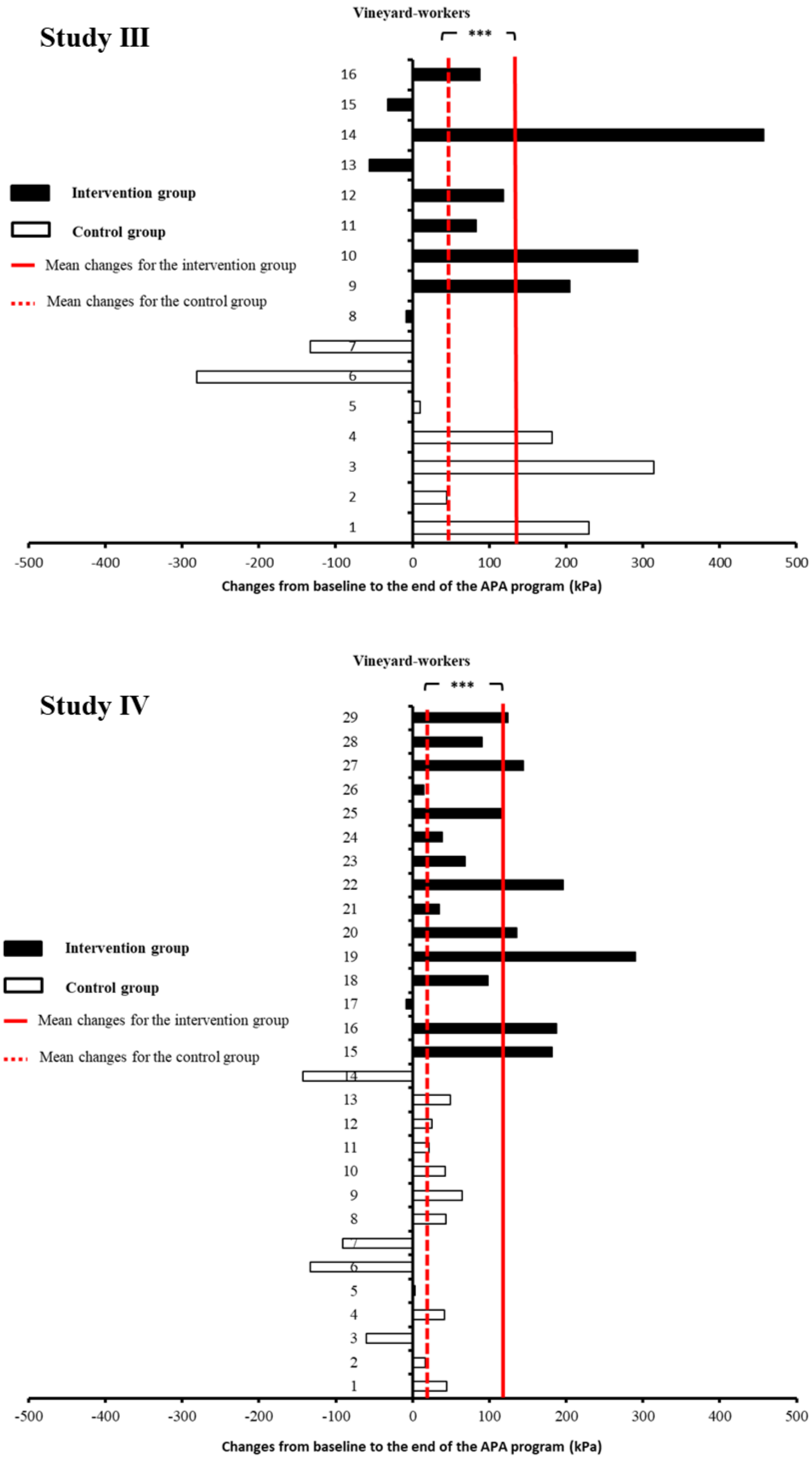

Figure 19. Changes from baseline to the end of the program for both studies (Study III : at the top ; Study IV: at the bottom), each vineyard-worker of the control group (white bar) and intervention group (black bar) for pressure pain sensitivity. Mean changes for the control group are represented by the dotted red line while mean changes for the intervention group are represented by the continuous red line. *P < .05; **P < .01.

DISCUSSION

The aim of this PhD thesis was hence to build effective actions to prevent WMSD symptoms of the low back among vineyard-workers. To achieve this goal, this PhD thesis was organized in two complementary sections, (1) a field ergonomic work exposure analysis and (2) the design, implementation and evaluation of a workplace APA program. The main findings of this PhD thesis are discussed in this chapter.

1. Field ergonomic work exposure analysis

Pruning activity is commonly performed between November and March each year. Using pruning shears, pruning activity consists in selecting two branches from the vine plant which will give grapes. Of note, a typical pruning work shift lasts approximately 7.5 hours per day, i.e. between 80 to 130 vine plants per hour or 600 to 1000 vine plants per day. So, this winter activity makes it possible to control the vine-growth and largely determines the quantity and quality of the harvest. For this reason and because pruning represents half the physical workload of the year, the field ergonomic work exposure analysis was focused on this workload activity.

a) Self-rated musculoskeletal pain during pruning activity and kinematic analysis

In Study I, perceived musculoskeletal pain intensities were rated subjectively twice a day (before and after the working day) by 11 vineyard-workers over 22 anatomical locations during a working week of pruning activity. First, results showed that pruning activity was associated with the presence of musculoskeletal pain over the elbows and the wrists. Interestingly, in numerous experimental studies the association between musculoskeletal pain over the hand-arm system and the physical demand of the pruning activity was already clearly established (Roquelaure et al. 2002; Roquelaure et al. 2001; Roquelaure et al. 2004; Wakula et al. 1999). Indeed, this activity commonly requires more than 30 cuts of pruning shears/minute (Roquelaure et al. 2002 ; Meyers et al., 2001) and requires repetitive and forceful wrist postures that increase the risk of WMSD symptoms over this anatomical location (Roquelaure et al. 2002 ; Meyers et al., 2001). Results further showed (1) that the low back was the most painful anatomical region and (2) that the perceived pain intensities for this anatomical location significantly increased throughout the working day. This latter finding confirmed the results reported by Bernard and colleagues (2011) that the pruning task *per se* could increase the risk of WMSD symptoms over the low back (OR= 1.347). These authors hypothesized that the presence of the pruning shears batteries on the low back and the "postural constraints" of this task could explain this association. At this point, however, these authors did not use any of the three common physical exposure assessment tools, i.e. subjective self-reports, observational methods or direct measurements, to test these hypotheses (David 2005; Spielholz et al. 2001; van der Beek and Frings-Dresen 1998). Moreover, to the best of our knowledge, no ergonomic work exposure analysis focusing on the kinematics of the low back during pruning activity has been previously performed. This lack of knowledge on potential risk factor for WMSD symptoms over the low back associated with the mild to moderate pain experienced over this anatomical location among the vineyard-workers (Jones et al. 2007) prompted to focus the field work exposure analysis on the low back area. To do so, Study I consisted in the video-recordings of pruning activity. The choice of video-recordings in Study I was guided by the advantages inherent to its use. First, video-recording is a validated tool frequently employed to identify and to estimate the biomechanical exposure on the back, e.g. trunk posture angles and movements performed during working activities (Li and Buckle 1999; van der Beek and Frings-Dresen 1998 ; Paquet et al. 2006). Therefore, results of Study I confirmed the conclusions made by Bernard and colleagues (2011) that postural constraint of pruning activity actually increased the risk of WMSD symptoms over the low back. Indeed, results of Study I attested exposure to trunk-thigh postures considered as “extreme” during the performance of this activity, a well-known risk factor of WMSD symptoms over the low back area (Burdorf et al. 1997; Hoogendoorn et al. 1999; Punnett et al. 1991). The second advantage of using video-recording is that, in real-work conditions, it provides insightful information on the working method, i.e. on how the vineyard-workers cope with the demanding task and how they interact with their environment (Major and Vézina 2015; van der Beek and Frings-Dresen 1998). Interestingly, this information can be further used in a focus group to confront workers with their own activities, to compare different strategies, to encourage the sharing of experience and the transfer of knowledge (Asan and Montague 2014; Brandt et al. 2015; Le Bellu and Le Blanc 2012; Major and Vézina 2015). Taken together, this information can serve to build a knowledge sharing basis to be integrated into meaningful and tailored WMSD prevention programs (Asan and Montague 2014; Brandt et al. 2015; Hanse and Forsman 2001; Major and Vézina 2015). However, it is also important to bear in mind that the use of video-recordings also presented limitations especially regarding the assessment of dynamic postures (Burton, Organization, and others 2010; Marras and Karwowski 2006; Teschke et al. 2009; van der Beek and Frings-Dresen 1998) such as those performed by vineyard-workers during pruning. Indeed, during this activity, the postures adopted by vineyard-workers could lead them not to be in the ideal viewing angle for the observers.

This phenomenon highlighted by Van der Beek and Frings-Dressen (1998) can result in difficulties to accurately estimate trunk forward bending and trunk rotation (Marras and Karwowski 2006; Teschke et al. 2009; Paquet, Punnett, and Buchholz 2001; van der Beek and Frings-Dresen 1998) yet well-known to be also associated with an increased risk of WMSD symptoms over the low back (Bernard et al., 1997; da Costa and Vieira 2010; Morgan and Mansfield 2014). Therefore, these difficulties led to the implementation of Study II. In the latter, trunk kinematics were recorded among 15 vineyard-workers using direct measurement methods, i.e. three-dimensional embedded inertial sensors during 12 minutes of pruning. This direct measurement method provided better precision and accuracy than video-recordings (Burdorf et al. 1997; Burton, Organization, and others 2010; Paquet, Punnett, and Buchholz 2001; Teschke et al. 2009). The results of Study II first confirmed that pruning activity was associated with the adoption of trunk forward bending for relatively long periods of time. For instance, vineyard-workers spent more than 50% of the 12 minutes of pruning with the trunk bent forward more than 30°. To go further, as illustrated in Figure 20, the percentage of the working time spent with the trunk bent forward during pruning was at least three time superior to those reported in studies among blue-collar workers (Lagersted-Olsen et al. 2016; Villumsen et al. 2015), nurses (Freitag et al. 2007; Schall, Fethke, and Chen 2016) and workers in school (Wong, Lee, and Yeung 2009). Of note, to our knowledge, only two studies (1) among 10 disassembly car workers in Sweden (Kazmierczak et al. 2005) and (2) among 24 daycare givers (Labaj et al. 2016) reported similar duration of trunk forward bending greater than 60° (Figure 20B) than vineyard-workers involved in Study II. More interestingly, the use of three-dimensional embedded inertial sensors in Study II highlighted that pruning activity paired trunk forward bending and trunk rotation. As shown in Figure 21, vineyard-workers spent 51% of the 12 minutes of pruning with the trunk rotated more than 10°, which is roughly similar to other occupational workers exposed to heavy physical workload (Raffler et al. 2017). To go further, similar postures pairing trunk forward bending and trunk rotation have been previously observed in other occupational settings such as among nurses (Freitag et al. 2007), paramedics (Prairie and Corbeil 2014), occupational drivers (Raffler et al. 2017) and among other blue-collar workers (Teschke et al. 2009), i.e. in occupational settings presenting high incidence and prevalence of low back WMSDs (Davis and Kotowski 2015; Menzel 2004; Oranye and Bennett 2017).

b) Duration of trunk forward bending, trunk rotation, low back pain intensity and pain sensitivity.

The second aim of Study II was to investigate whether and to what extent the duration of trunk forward bending or trunk rotation was associated with perceived pain intensity and pressure pain sensitivity over the low back. Interestingly, results of Study II first showed no significant association between the duration of trunk forward bending and musculoskeletal pain intensity. Due to the lack of experimental studies addressing this issue and due to the different types of experimental designs (cross-sectional and prospective designs), comparison with the existing literature remains rather difficult. For instance, results of Study II were in line with those reported recently in the cross-sectional study by Villumsen and colleagues (2015) among almost 200 blue-collar workers. In the latter, the authors did not observe any significant association between the time spent in different trunk forward bending cut-off angles (i.e. >30°, >60° and >90°) and self-reported LBP intensity. Results from prospective studies that commonly allow to establish the existence of a temporal relationship between outcomes (Rothman and Greenland 2005) are more controversial. On the one hand, the study by Lagersted-Olsen and colleagues (2016) among almost 700 blue-collar workers assessing the risk of occurrence and aggravation of WMSD symptoms over a one year monthly follow-up period concluded for the absence of association between these outcomes and the duration of trunk forward bending (Lagersted-Olsen et al. 2016). On the other hand, these findings were not in line with those of Hoogendoorn and colleagues (2000) and Coenen and colleagues (2013). Indeed, in their prospective study, Hoogendoorn and colleagues (2000) showed among more than 800 blue-collar workers without LBP at baseline that trunk forward bending greater than 60° more than 5% of the time was significantly associated with the occurrence of LBP at the one year follow-up (relative risk = 1.48). First, the difference between these two studies may stem from the duration of the follow-up period (i.e. 3 years for Hoodendoorn and colleagues (2000) *versus* 1 year for Lagarsted-Olsen and colleagues (2016). Second, this difference can also result from the additional analysis performed by Hoogendoorn and colleagues (2000) that revealed that the association between trunk forward bending and occurrence of LBP was stronger among workers who had been in their current job for more than five years. This last finding suggests that the cumulative exposure to trunk forward bending and more precisely the accumulation of time spent with the trunk bent forward greater than 60° over years of working activity may increase the risk of occurrence of WMSD symptoms over the low back. This could partly explain the presence of these symptoms among all the vineyard-workers who at the time of Study II had had more than five years of vineyard experience (mean vineyard experience = 18.7 ± 6.6 years) and who spent 22% of the time with the trunk bent forward more than 60° (Figure 22). Further, Hoogendoorn and colleagues (2004) also reported that when the threshold of 5% of the time spent with the trunk bent forward more than 30° was exceeded, the risk of SA increased. So, as shown in Figure 23, it is noteworthy that vineyard-workers largely exceed this threshold, making this population at high risk of SA. Therefore, even if these results suggested that the postures adopted during pruning activity provoke a risk of occurrence of WMSD symptoms over the low back and thus absences for sick leave, this relationship should be questioned in further prospective studies with long-term follow-up (Villumsen et al. 2015) and among newly-hired workers (Hoogendoorn et al. 2000 ;Van Nieuwenh et al., 2004).

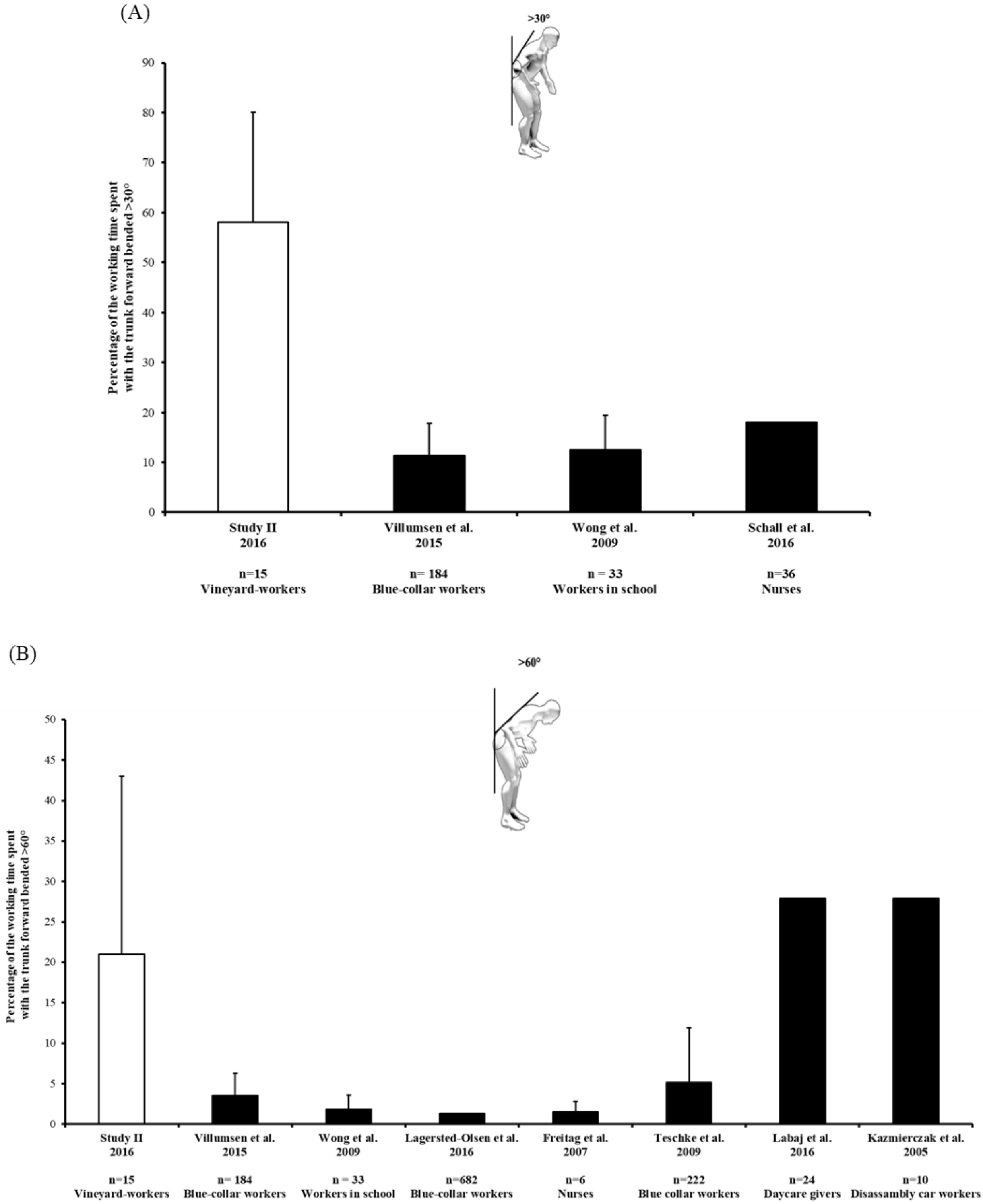

Figure 20. Mean and standard deviation of the percentage of working time spent in each trunk forward bending cut-off angles, greater than 30° (A) and greater than 60° (B) in Study II compared to other cross sectional studies among workers.

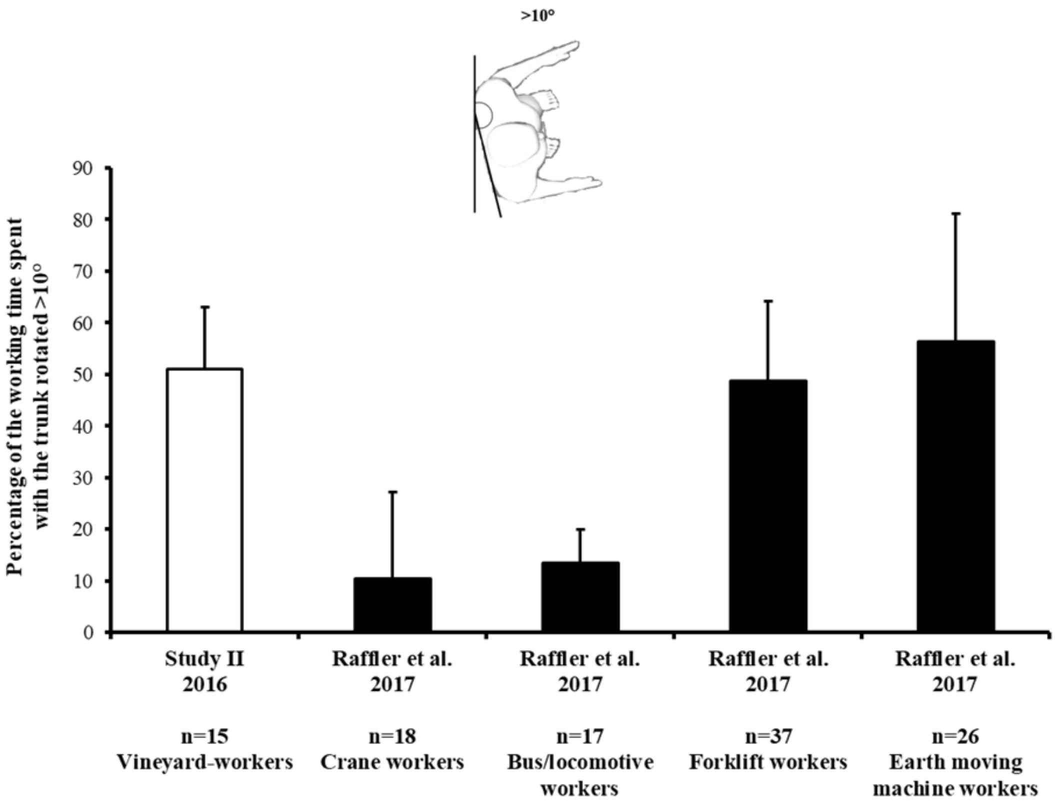

Figure 21. Mean and standard deviation of the percentage of working time spent with the trunk rotated more than 10° in Study II compared to other cross sectional studies among workers.

Further, insofar as the association of trunk forward bending and trunk rotation is recognized to increase the load on the lumbar spine (Wai et al. 2010), and assuming that trunk rotation is likely to increase disc compression and shear forces (Waters et al. 1993), Lagersted and colleagues (2016) hypothesized that the combined duration of trunk forward bending and trunk rotation could be a risk factor for the development or the aggravation of WMSD symptoms over the low back. At this point, however, this hypothesis was not confirmed in Study II as no significant association was demonstrated whatever the degree of forward bending or twisting and whatever the duration of exposure analyzed. One possible explanation for this lack of association may be perceived through the relatively low self-rated LBP intensity reported by the vineyard-workers, and the relatively high PPTs which were similar to those reported among healthy subjects (Balaguier, Madeleine, and Vuillerme 2016a; Binderup et al. 2011). Indeed, these findings argued in favor of a “floor-effect” (Ge et al. 2014), i.e. that musculoskeletal pain intensity was too low to detect any association. In the same vein, it is not excluded that this lack of association was due to a “healthy worker effect”. In other words, it is possible that the vineyard-workers having suffered the most pain may have left the profession making participants of Study II “healthy survivors” (Villumsen et al. 2015).On the other hand, it seems unlikely that the duration of trunk forward bending or trunk rotation has modified the direction of the association. Indeed, as previously illustrated in Figure 20 and Figure 21, the percentage of the working time spent with trunk bent forward or rotated during pruning was at least three time superior to those of numerous other studies among blue-collar workers (Lagersted-Olsen et al. 2016; Raffler et al. 2017; Villumsen et al. 2015), nurses (Freitag et al. 2007; Schall, Fethke, and Chen 2016) and workers in school (Wong, Lee, and Yeung 2009).

c) Conclusions

The first part of this PhD thesis discusses the findings of two studies assessing the effects of pruning activity on WMSD symptoms and assessing, in real work conditions the kinematics of the low back during the performance of pruning activity. Results of these two studies have confirmed the presence of WMSD symptoms over the low back during the performance of pruning activity. These findings corroborate the observations made by the top managers of the Château Larose-Trintaudon, i.e. that pruning activity was a source of musculoskeletal complaints among vineyard-workers. Then, the two methods used in Study I and Study II (i.e. observational and direct measurement methods) demonstrated the adoption over a long period of time of trunk forward bending and trunk rotated postures subsequently leading to a high risk of WMSD symptoms over the low back and a risk of absence for sick leave. Further, the high participation rate which reaches 60% of the workforce and the standards imposed in this geographical region (Bulletin official du Ministère de l'Agriculture et de l'Alimentation, recommendations of 26th August 2015) such as those affecting the height of the vine plant or the space between rows leave little place for variability between wine-producing companies and consequently reinforce the generalizability of findings of both studies (Image 1). As a whole, these findings gave a new insight on how vineyard-workers cope with pruning activity but, above all, lend support to the implementation of a WMSD symptom prevention program that specifically targets the low back area among these workers.

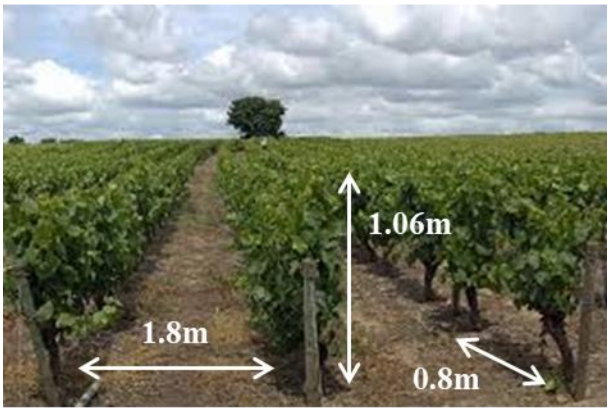

Image 1. Standards for the vine rows in the Médoc area.

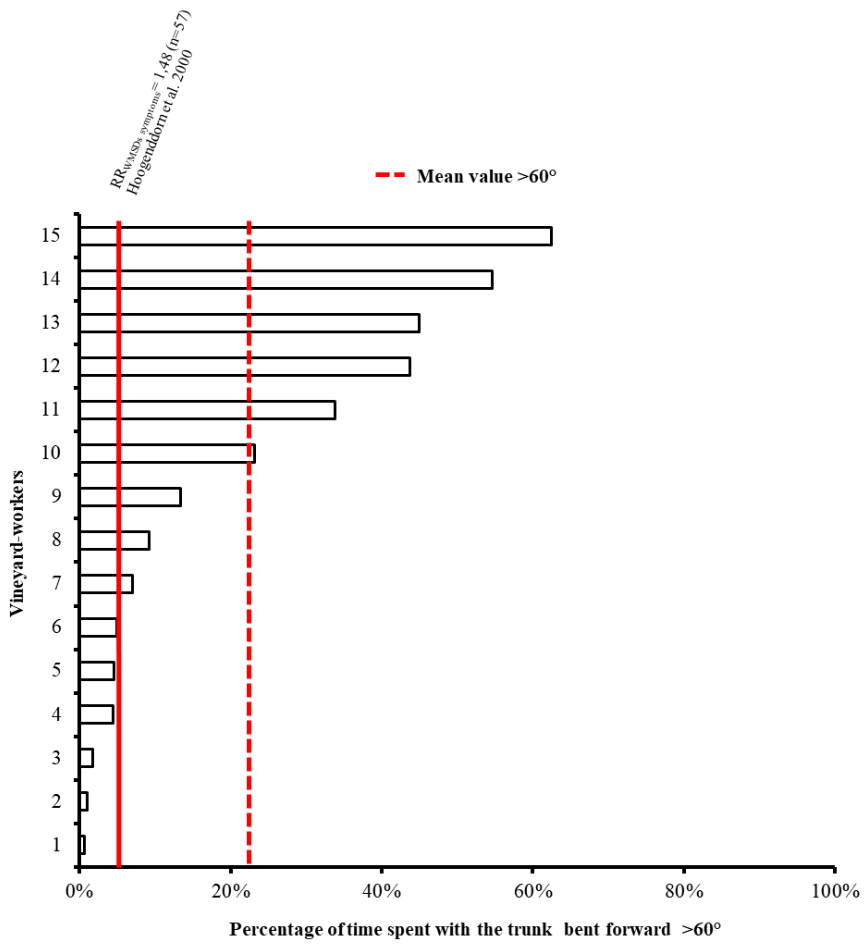

Figure 22. Mean percentage of time spent with the trunk bent forward more than 60° for each vineyard-workers and all the vineyard-workers (dotted red line) and comparison with the relative risk of occurrence of WMSD symptoms (red continuous line) reported by Hoogendoorn and colleagues (2000).

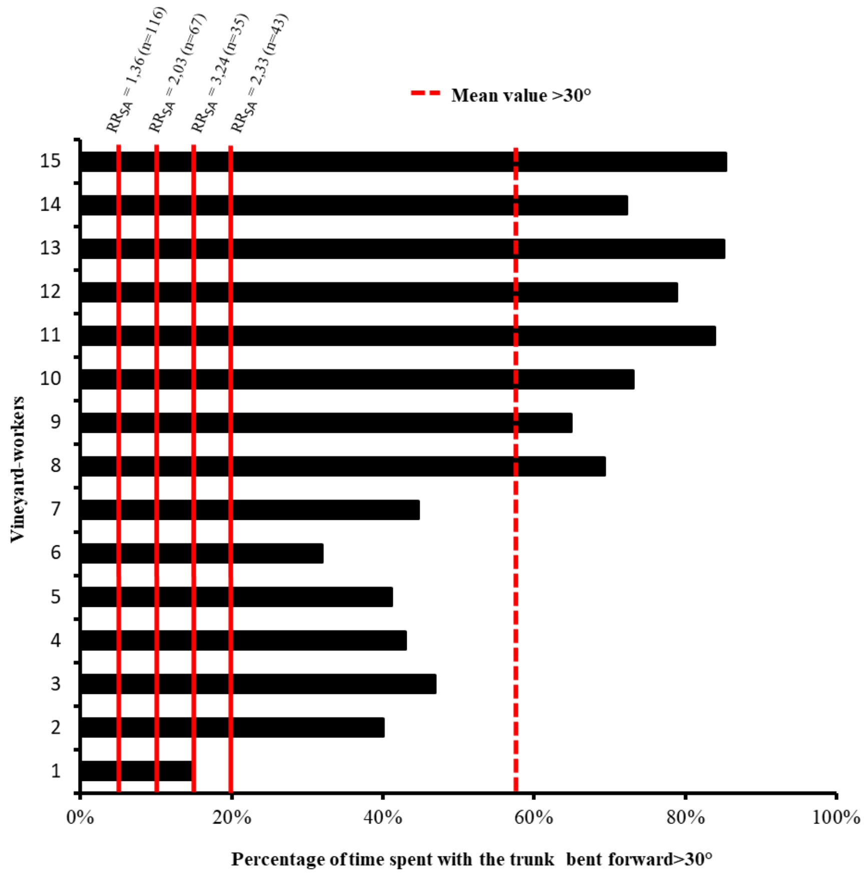

Figure 23. Mean percentage of time spent with the trunk bent forward more than 30° for each vineyard-worker and comparison with the relative risk of absence for sick leave due to WMSD symptoms (red continuous line) reported by Hoogendoorn and colleagues (2000).

2. Development of an adapted solution to prevent work-related musculoskeletal disorders in wine-producing companies.

Of note, the scientific literature still remains unclear as to under which circumstances a theoretical effective WMSD prevention solution is actually more relevant than another (Simoneau et al. 1996; Coutarel et al. 2010). However, numerous authors suggest that the implementation of such a program must be preceded both by identification of WMSD risk factors (done in PhD thesis Part I) and by taking into consideration the specific context of the company, its health policy and the actions already implemented or tested (Coutarel et al. 2010; Goetzel et al. 2007; Henning et al. 2009; Oakman, Rothmore, and Tappin 2016; van der Beek and Frings-Dresen 1998).

Thus, at the Château Larose-Trintaudon, several technical solutions, such as ergonomic seats, have been previously tested to prevent WMSDs of the low back (Image 2). Following several unsuccessful trials, however, vineyard-workers have decided not to adopt these solutions since they were not suitably adapted to the constraints of their work. For instance, vineyard-workers pointed out the difficulties to move along the vine rows in case of rain or after the passage of tractors working the soil.

Image 2. Example of an ergonomic seat implemented among the Château Larose-Trintaudon vineyard-workers

Other ergonomic seats have been proposed, but the organization needed to purchase them and the price (i.e. around 6000 euros) of such solutions did not allow their evaluation in *in situ* tests to be performed (Image 3). So, although these solutions seem to be of interest to vary trunk postures over a working day, no scientific studies have, to date, guaranteed their positive effects on WMSD symptoms over the low back area. Another interesting technical approach could have consisted in changing the workstation, i.e. the vineyard height to increase the time spent in neutral postures. Indeed, Kato and colleagues (2006) assessing the effects of five trellis systems on trunk forward bending angle during pruning activity have reported the possibility to decrease the risk exposure for the low back, i.e. to decrease the time spent adopting trunk postures considered as “extreme”. However, this solution was impossible since the method of planting in this region is governed by strict standards regarding vineyard height, space between vine rows and because it involved rethinking all working methods and processes. Thus, according to the regulations in force, the space between two vine rows must be at least 1.8 meters, the space between two vine plants must be at least 0.8 meter and the vineyard-height must not exceed 1.06 meters (i.e. 60% of the distance between two rows)

(Bulletin official du Ministère de l'Agriculture et de l'Alimentation, recommendations of 26th August 2015).

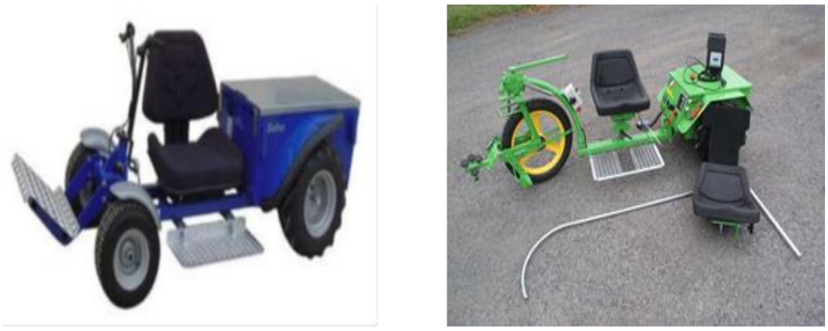

Image 3. Example of ergonomic seats envisaged in the Château Larose-Trintaudon.

Through these examples, it is easy to understand that some risk factors such as repetitiveness, trunk forward bending or trunk rotation could not be eliminated from the working environment of vineyard-workers. Therefore, numerous authors have pointed out the necessity to identify other elements of the work system that could be modified and could balance the negative consequences of prolonged exposure to these risk factors (Carayon, Smith, and Haims 1999).

With this in mind, one solution that has gained interest over the last several years in other occupational settings, such as among office workers (Andersen et al. 2014; Andersen, Jørgensen, et al. 2008; Andersen, Kjaer, et al. 2008; Andersen et al. 2010), healthcare-workers (Barene, Krustrup, and Holtermann 2014; Christensen et al. 2015; Jakobsen et al. 2015) or industrial workers (Gram et al. 2012; Jay et al. 2015; Nassif et al. 2011; Pedersen et al. 2013; Sundstrup et al. 2016), has been the implementation of a workplace APA program. The common point between most of these occupational settings that suggested the relevance of implementation of such a solution among the Château Larose-Trintaudon vineyard-workers was their exposure to heavy physical workload. Indeed, an imbalance between physical capacities and exposure to work-related physical factors was one of the reasons put forward to explain the risk of WMSD symptoms among these populations (Holtermann et al. 2010; Hamberg-van Reenen et al. 2006). Therefore, to counterbalance this risk a research group has developed a concept of intelligent physical exercise training, i.e. adapted physical activity (Holtermann et al. 2010; Sjogaard et al. 2016). To summarize, this concept based on sports science training principles (e.g. graded activity, individual recommendations) and an adaptation of physical activity to work exposure and workers' characteristics has largely demonstrated its health-enhancing effects (Sjogaard et al. 2016) justifying its development and implementation among vineyard-workers.

3. Workplace supervised adapted physical activities program

a) Design, implementation and evaluation of the solution – A pilot study

The aim of Study III was to design, implement and evaluate a worksite supervised APA. First, as numerous studies reported that low trunk muscle endurance and flexibility were reported among workers with WMSDs over the low back (Alaranta et al. 1995; Demoulin et al. 2006;

Ekedahl, Jönsson, and Frobell 2012; Hamberg-van Reenen et al. 2006; Latimer et al. 1999; Luoto et al. 1995; Sadler et al. 2017; Strøyer and Jensen 2008), the APA program was specifically designed to enhance these neuromuscular capacities. Then, the program was implemented and evaluated among 16 volunteer vineyard-workers who were allocated into an intervention group (n=9) or a control group (n=7). Results of Study III showed that, at baseline, for the flexibility tests, volunteer vineyard-workers (both control and intervention groups, n= 16) achieved performances considered as "normal" in the literature (Tveter et al. 2014). For instance, regarding the finger-to-floor test in which participants standing on box were asked to bend forward as far as possible, roughly similar performances were observed between vineyard-workers and age-matched healthy controls (Tveter et al. 2014), i.e. 43.2 cm *versus* 41.5 cm. On the other hand, regarding trunk muscle endurance, results of Study III suggested that the performances could be considered as "low" in the scientific literature (Adedoyin et al. 2011; Demoulin et al. 2006; Moreau et al. 2001; Stewart, Latimer, and Jamieson 2003; Tekin et al. 2009). Indeed, among the volunteer vineyard-workers, the trunk extensor endurance time was close to 70 seconds, while mean value for age-matched healthy control was fixed approximately about 100 seconds in the study by Adenoyin and colleagues (2011) presenting age normative values for this test. At the end of the APA program, while no significant changes in trunk muscle endurance and flexibility among vineyard-workers of the control group was observed, a significant increased for these neuromuscular capacities in the intervention group was reported: they increased their performance for the finger-to-floor test by 6 cm (i.e. 16%), and by 68 and 142 seconds (i.e. 128% and 220% of increase) respectively for the trunk extensor and flexor endurance tests. Positive effects of workplace APA program on trunk muscle flexibility and endurance have been previously reported in other occupational settings (Mayer et al. 2015; Nassif et al. 2011; Sihawong, Janwantanakul, and Jiamjarasrangsi 2014). However, the increase in trunk muscle neuromuscular capacities observed in Study III largely exceeded those reported in these studies. For instance, Nassif and colleagues (2011) implementing an eight-week supervised APA program roughly similar to ours with three weekly sessions lasting 60 minutes in groups of up to six assembly line workers reported an increased endurance time of 6 and 12 seconds respectively for the trunk flexor and extensor endurance tests. To go further, despite a baseline level considered as mean (i.e. 87 seconds) an increase of approximately 10 seconds was reported after 24 weeks of an APA program among firefighters without LBP for the trunk extensor endurance time (Mayer et al. 2015). Taken together, these results underline the necessity to question the relationship between the increase in neuromuscular capacities and WSMD symptoms. In other words, is the increase in trunk muscle flexibility and endurance observed among the vineyard-workers of the intervention group clinically meaningful? Results in the literature are still controversial. For example, in the study by Luoto and colleagues (1995) among 126 workers without WMSD symptoms over the low back at baseline, the risk of developing such symptoms during the one-year follow-up period was 3.4 times higher among workers sustaining less than 58 seconds compared to those sustaining more. However, in a systematic review assessing whether low trunk muscle endurance was predictive of LBP, Hamberg-van Reenen and colleagues (2008) have reported inconclusive evidence for a relationship between these outcomes. Sadler and colleagues (2017) in their recent systematic review of prospective cohort studies go even further, concluding for no association between trunk muscle endurance or finger-to-floor and the occurrence of LBP. Although it is clear that the heterogeneity of participants recruitment (i.e. with and without LBP at baseline) may have affected this conclusion (Sadler et al. 2017), it seems difficult to define a clinical threshold above which the vineyard-workers would reduce their risk of WMSDs over the low back.

Nevertheless, it seems important to us not to consider the clinical significance of the increase only from the point of view of the risk of occurrence of LBP. For instance, benefits of increased trunk muscle flexibility and endurance can also be seen as a way to limit the aggravation of WMSD symptoms, i.e. pain intensity. Interestingly, the prospective study by Stroyer and colleagues (2008) assessing the association between the level of physical fitness and LBP intensity at 30 months follow up among healthcare-workers revealed a significant association between trunk extensor endurance time and LPB intensity. Indeed, they reported that workers sustaining less than 158 seconds at baseline were exposed to a higher risk of increased LBP intensity than those sustaining more than this endurance time (OR=2.71). Thus, while trunk extensor endurance time at baseline among the vineyard-workers of the intervention group was far from this threshold (i.e. 53 seconds), at the end of the APA program, performances get closer (i.e. 122 seconds). To go further, at the end of the APA program, two of the nine vineyard-workers exceeded this threshold and four of them achieved performances between 105 and 130 seconds. Therefore, the increase in trunk extensor endurance time could be considered as clinically meaningful since the APA program enabled vineyard-workers to get closer to the threshold, decreasing the risk of aggravation of perceived pain intensity. Finally, Stroyer and colleagues (2008) did not report any other significant association, e.g. between trunk flexor endurance time or trunk muscle flexibility and risk of increase LBP intensity. This finding sheds light on the importance of trunk endurance exercises in APA program to limit the aggravation of WMSD symptoms. This finding further highlights the necessity of prospective studies to get a deeper insight into the relationship between trunk neuromuscular capacities (trunk extensor and flexor endurance times and trunk muscle flexibility) and perceived LBP intensity.

Finally, benefits of increased trunk muscle endurance and flexibility can also be seen as a way to limit muscle fatigue and indirectly the risk of WMSD symptoms. In this sense, Marras and Karwoski (2008) have concluded that an 8-hour working activity, such as that performed by vineyard-workers, may lead to a fatiguing process decreasing muscular function (Figure 24). The authors have also suggested that this fatiguing process may be exacerbated by the daily repetitive performance of working activity and the lack of a sufficient recovery period subsequently increasing the risk of WMSD symptoms. This hypothesis in which short rest duration for example between cycling flexion loads increased the risk of WMSD symptoms has been confirmed in *in vivo* animal studies (Hoops et al. 2007). Indeed, three groups of *in vivo* felines had to perform six bouts of cycling lumbar flexion lasting 10 minutes and separated by different rest durations (i.e. 5 versus 10 min versus 20 min). Thus, after the performance of this task and during seven hours, muscular activity of the erector spinae muscles was recorded. Interestingly, the 5 and 10 min rest groups showed a hyper-excitability over their erector spinae muscles during the recovery period exhibiting a neuromuscular disorder and an increased risk of fatigue while the 20-minute rest group was free of this phenomenon. It seems that the fatiguing process could be counterbalanced by effective APA program, like the one implementing among vineyard-workers. For instance, Sundstrup and colleagues (2015) have reported that a 10-week resistance training program targeting the hand-arm system among slaughterhouse workers was effective to increase the time to reach fatigue during the performance of a fatiguing simulated working task. This finding, even if it has to be verified over the low back area, argued in favor of increased fatigue resistance capacity subsequently suggesting a faster recovery and that an APA program would be able to reduce the potential imbalance between individual capacity and work demand (Holtermann et al. 2010).

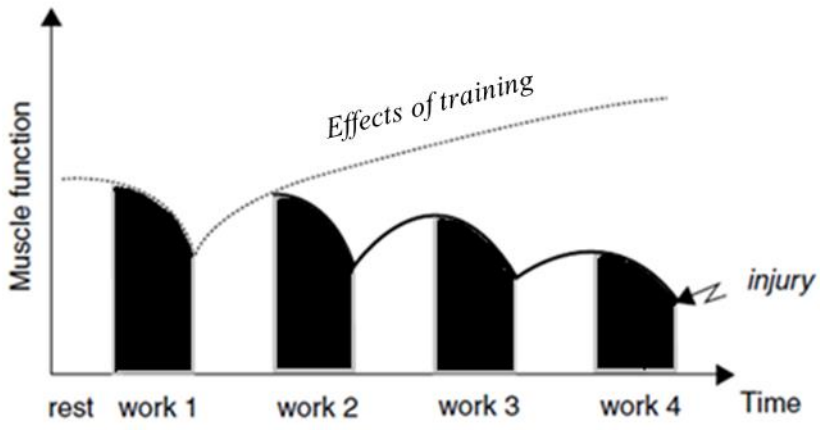

Figure 24. Muscle function in relation to work and recovery, adapted from Marras and Karwoski (2008).

A second objective of Study III was to assess the effects of the APA program on musculoskeletal pain sensitivity, i.e. on PPT. At baseline, vineyard-workers of the control group experienced higher PPT than the intervention group (496.7 kPa *versus* 284.0 kPa). Even if this difference may stem from a selection bias due to the non-randomized controlled design of the study, this significant difference may reinforce the interest of Study III. Indeed, numerous authors have suggested that workplace physical activity programs tend to reach participants with higher SEP, already sufficiently active, not in pain, i.e. tend to reach workers with low risk of WMSD symptoms (Linnan et al. 2008; Macniven et al. 2015; Quintiliani et al., 2007). On the other hand, results of Study III suggest that workers with the lowest PPT, i.e workers at higher risk of WMSD (Binderup et al. 2011; Madeleine et al. 2003), were more prone to participate in the APA program. To go further, the reported PPTs over the low back in the intervention group were similar to those reported among cleaners with higher risk of long-term sick leave (Binderup et al. 2011) putting forward the necessity of assessing the effects of the APA program on PPT among this population. In this sense, PPT over the low back for the intervention group significantly increased by 128 kPa throughout the eight weeks duration of the APA program. Interestingly, two recent studies assessing the reliability of pressure algometry over the low back of healthy subjects and vineyard-workers reported a minimum detectable change of approximately 120kPa (Balaguier, Madeleine, and Vuillerme 2016a, 2016b). The increase observed at the end of the APA program was also in line with a recent study reporting an increase of 196 kPa for PPT over the low back of office-workers after an eight-week home based APA program targeting trunk muscles (Kim, Kim, and Cho 2015). Positive effects of workplace APA programs on PPT were also observed over the trapezius muscles (Andersen et al. 2014; Andersen et al. 2012; Nielsen et al. 2010; Li et al. 2017; Ylinen et al. 2005). For instance, PPT were significantly increased by 122 kPa in two unsupervised resistance training groups of women office-workers after a 6-week program (Li et al. 2017). In the same vein, Andersen and colleagues (2014) showed that, after a 10-week worksite supervised APA program, PPT increased by 128 kPa and 145 kPa over the upper and lower trapezius muscles, respectively. Altogether, these findings associated with the elevated PPT observed at the end of the program (Binderup, Arendt-Nielsen, and Madeleine 2010; Binderup et al. 2011), lends support for the clinical significance of the PPT increase observed at the end of this program. Of note, the choice of using pressure algometry measures instead of subjective rating scales (e.g. numeric rating scale or visual analogic scale) to assess the effects of the APA program on musculoskeletal pain was motivated by the recent validation of this tool among vineyard-workers (Balaguier, Madeleine, and Vuillerme 2016b). Then, pressure algometry was also widely acknowledged to provide insightful information on the sensitivity of the nociceptive system, i.e. on pain mechanisms (Arendt-Nielsen and Yarnitsky 2009; Pavlaković and Petzke 2010). Therefore, altogether, these findings indicated that the nociceptive system could be positively modulated, i.e. less sensitized by the APA program (Arendt-Nielsen and Graven-Nielsen 2008). This interpretation was reinforced by (1) the absence of significant change for PPTs in the control group and (2) by recent studies emphasizing that lower PPTs were commonly observed after the performance of daily occupational activities (Madeleine et al. 2003; Park and Yoo 2013; Yoo And and Yoo 2014). For instance, Yoo and Yoo (2014) have reported that after a 30-minute assembly line task, PPTs of the upper and middle trapezius muscles were significantly decreased. Several mechanisms, i.e. mechanical or chemical mechanisms may act in concert to explain the PPT increase. Thus, during an APA program, Ylinen and colleagues (2005, 2007) suggested that the activity of nociceptors may be inhibited by the increased activity in afferent and efferent motor pathways. More recently, Lunde and colleagues (2017) reported that an eight-week program including aerobic or resistance training among office workers and road workers was likely to decrease the level of inflammatory biomarkers known to be elevated in myalgic muscles of repetitive manual workers (Larsson et al. 2008). This finding suggests that an APA program induced positive change in the nociceptors environment that could, in turn, explain the decrease in pain sensitivity observed among vineyard-workers of Study III.

Finally, one of the most promising results of Study III was the full compliance rate observed over the APA program duration. On the one hand, the study design, i.e. a non-randomized controlled trial, was a pre-requisite to enhance the compliance of such a program (Kwak et al. 2006; Nagamachi 1995). On the other hand, implementing a workplace program with high compliance rate remains rather challenging. Indeed, despite roughly similar programs in terms of duration (10 to 20 weeks) and frequency (2 to 3 sessions per week), authors can either report low compliance rate, i.e. around 40% (Hagberg et al. 2000; Jakobsen et al. 2016; Viljanen et al. 2003), medium compliance rate, i.e. around 60% (Andersen et al. 2011; Andersen et al. 2014; Jay et al. 2011, 2015; Ylinen et al. 2003) or high compliance rate, i.e. around 80% (Andersen et al. 2008; Sundstrup et al. 2014; Zebis et al. 2011). So, why is it crucial to get closer to this full compliance rate? First, a full compliance rate protects against a Type III error, i.e. concluding that the intervention was not effective while there was no intervention (Basch et al. 1985). Second, it has been documented that the effectiveness of an APA program on neuromuscular capacities or musculoskeletal pain is inseparable from regular training (Jakobsen et al. 2016; Jay et al. 2015; Linton, Hellsing, and Bergström 1996; Nikander et al. 2006; Sjøgaard et al. 2016). Thus, Jakobsen and colleagues (2016) over a 10-week supervised APA program among healthcare-workers (n=111) exhibited that a high compliance rate (i.e. performing more than two sessions per week) lead to a significantly larger decrease in musculoskeletal pain intensity (-1.46 *versus* -0.9, p=0.04) than low compliance rate (i.e. performing less than 2 sessions per week). To go further, getting closer to this full compliance rate is also a major concern for the employer funding the program and for the sustainability of the latter.

Taken together, these findings support the idea that the worksite supervised APA program designed and implemented in Study III was effective to increase trunk muscle endurance and flexibility as well as to decrease pain sensitivity over the low back. Then, results argued in favor of clinically meaningful changes from baseline to the end of the APA program especially for the trunk extensor muscle endurance and put forward a potential clinical target to limit the increase in musculoskeletal pain for further studies. Recent literature also highlights the potential positive effects of the APA program to prevent the apparition of accumulated fatigue and subsequently preventing the risk of aggravation of WMSD symptoms over the low back. Study III has also demonstrated that a worksite supervised APA program was feasible among vineyard-workers and has demonstrated an optimistic prediction of the compliance rate among nine of them. Results of Study III finally suggest that this worksite APA program should be implemented and evaluated on a broader scale to determine whether its effects are reproducible among a larger sample size of vineyard-workers.

b) Implementation on a broader scale

Effectiveness evaluation

In the year following the implementation of Study III, the APA program was implemented simultaneously at the Château Larose-Trintaudon and at the Château Pichon-Longueville Baron (Study IV). Thus, the implementation of the APA program among 15 vineyard-workers in the intervention group working at two different wine-producing companies led to similar results than those reported in Study III among nine vineyard-workers from one wine-producing company. Indeed, at the end of the APA program, vineyard-workers of the intervention group significantly increased their flexibility (Finger-to-floor: 42.4 versus 37.1 cm ; Sit-and-reach: 30.4 *versus* 33.2 cm), their trunk extensor endurance time (81.9 sec *versus* 145.5 sec), their trunk flexor endurance time (117.7 *versus* 240.9 sec) and their PPT (462.7 *versus* 576.8 kPa). Moreover, for all the neuromuscular capacities and pain sensitivity changes from baseline to the end of the APA program were significantly larger among the intervention group than among the control group. Figure 15 to Figure 18 was built to visually compare results between Study III and Study IV and consequently provide a deeper insight on these results. Interestingly, Figure 15 to Figure 18 shows that in Study III as well as in Study IV all the vineyard-workers improved their trunk muscle endurance and flexibility. Hence, results of Study IV highlighted that vineyard-workers with the lowest neuromuscular capacities at baseline were those for whom the increase was the greatest (coefficient correlation range from -0.55 for the finger-to-floor test to -0.74 for the trunk extensor endurance test). These findings are of importance for the implementation of future intervention. Indeed, perceived self-efficacy and belief in ones capabilities are strong determinants for the adoption of healthy behaviors and predictive of physical activity maintenance (McAuley et al. 2003). Therefore, these results should be used to facilitate the commitment of new participants and to motivate participants over time.

Summative process evaluation

To question in depth the generalizability of the results of Study III, Study IV also raised the need for information on which components of the APA program may potentially explain the positive effects reported among the vineyard-workers. Indeed, numerous authors have highlighted the necessity to collect data on how the characteristics of the organization, the characteristics of the intervention and the satisfaction with the APA program received may potentially explain its effectiveness (Haims and Carayon 1998; Saunders, Evans, and Joshi 2005; Wierenga et al. 2013). For a better understanding of these characteristics, i.e. about the components or factors affecting the effectiveness, a valid approach performed in Study IV consisted in the implementation of a summative process evaluation (Saunders, Evans, and Joshi 2005).

As suggested in the literature (Roquelaure 2016; Saunders, Evans, and Joshi 2005; van der Beek et al. 2017; NIOSH, 2016), the process evaluation first focused on the characteristics of the organization, i.e. on the health and safety culture in both wine-producing companies. It is noteworthy that the organizational context in the Château Larose-Trintaudon and Château

Pichon-Longueville Baron demonstrated a strong involvement and experience in the implementation of workplace health promotion programs. In other words, in both wine-producing companies and at different organizational levels (top-managers, mid-level managers and workers), employees were already familiar with approaches aiming at improving their working conditions. Thus, it is probable that these antecedents have contributed to facilitate the implementation of the worksite supervised APA program in both companies and subsequently have contributed to its effectiveness. Indeed, numerous authors have pointed out that, to be effective, a workplace prevention program must be at least consistent with, if not fully integrated in, the company's health culture (Goetzel et al. 2014; NIOSH, 2016; Rojatz, Merchant, and Nitsch 2016; Verweij et al. 2012; Wierenga et al. 2013).

As also suggested by Henning and colleagues (2009), several months before the beginning of the APA program different informational presentations were organized in both companies. The latter specifically targeted the vineyard-workers of both vine-companies and allowed them to be officially informed about the purpose of the intervention, as well as the potential benefits of the APA program such as those observed on musculoskeletal pain intensity or physical capacities. These presentations brought the opportunity to present the role of each participant (i.e. vineyard-workers, middle and top managers, APA instructors and researchers) and to describe the general organization of the worksite APA program. All these components have been identified as relevant solutions to encourage the participation in WMSD prevention programs and subsequently as a necessary step to increase the program effectiveness (Henning et al. 2009; Hunt et al. 2007; Goetzel et al. 2014; NIOSH, 2016; Rojatz, Merchant, and Nitsch 2016; Wierenga et al. 2013). Finally, since a perceived supportive working environment is a pre-requisite for effective workplace APA program (Bredahl et al. 2015; Driessen et al. 2010; Jørgensen et al. 2016; Verweij et al. 2012; Wierenga et al. 2013), these presentations enabled top and mid-level managers to acknowledge among vineyard-workers the commitment of the vine-companies in the APA program and was a way to encourage them to participate.

Another important point to discuss regarding the APA program's effectiveness concerns the nature of exercises implemented and the role of the APA instructors. In this sense, it is important to emphasize that numerous authors have implemented during their worksite APA program only a limited number of exercises (Andersen and Zebis 2014; Dalager et al. 2015; Jakobsen et al. 2015; Jakobsen et al. 2016; Mayer et al. 2015; Zebis et al. 2011). For instance, Dalager and colleagues (2015) asked office-workers to perform nine specific strength training exercises over their 20 week-program, Mayer and colleagues implemented a set of five exercises among fire-fighters as did Zebis and colleagues (2011) among industrial workers. On the one hand, implementing a limited number of exercises presents advantages, including an easier and a more accurate control on program variables (i.e. on intensity and load) necessary to increase reproducibility of the exercises between studies (Garber et al. 2011). On the other hand, proposing a limited number of exercises also presents important barriers limiting the program effectiveness. First, the satisfaction with the program could be negatively affected by the lack of diversity between exercises (Andersen and Zebis 2014; Bredahl et al. 2015). For instance, in the study by Andersen and Zebis (2014), two thirds of the office-workers who performed only one neck strengthening exercise over 10 weeks were not satisfied with the intervention and further indicated that they would have appreciated a larger variety of exercises. To go further, even if compliance did not seem to be affected at short-term follow-up (Andersen and Zebis 2014), the monotony of the exercises may potentially decrease the latter in case of long-term APA program implementation (Andersen and Zebis 2014; Bredahl et al. 2015). However, in Study III as well as in Study IV, APA instructors were encouraged to implement a large variety of exercises (i.e. about 15 exercises respectively for trunk muscle endurance and flexibility), to use varied equipment such as swiss-balls, medicine-balls or dumbbells. Even if further studies addressing this issue are needed, the variety of exercises has contributed increasing the program effectiveness and that the diversity of exercises should be included as an outcome to assess the effectiveness of further programs. Altogether, this information argued in favor of a supervised APA program and emphasizes the necessity to work on motivational aspects to increase program effectiveness (Amireault, Godin, and Vézina-Im 2013). To reinforce this idea, numerous authors (Bredahl et al. 2015; Haims and Carayon 1998; van Berkel et al. 2013) have reported that non-compliant participants were more often those who perceived the program as not adapted to their abilities, difficulties and level. This finding highlighted that because the APA instructors design exercises targeting the relevant body parts and adapted to each participant the role played by these latter in the APA program effectiveness is not to be underestimated. Moreover, this discussion should not be continued without mentioning the positive effects of the APA program on vineyard-workers' well-being and social relationships. Indeed, the APA program was the occasion for vineyard-workers to perform strengthening and flexibility exercises in a positive atmosphere allowing the development of links, interaction and motivation between colleagues. This social interaction may have contributed to the improvement of well-being perceived by vineyard-workers at the end of the APA program and subsequently have contributed to the program effectiveness. These findings are in line with recent studies reporting that worksite APA programs can be seen as 'biopsychosocial' interventions (Andersen 2011,2017; Bredahl et al. 2015; Jakobsen et al. 2015, 2016; Sundstrup et al. 2014), hence particularly relevant to apprehend the multifactorial origin of WMSDs of the low back (Roquelaure 2016).

Finally, we also have to point out limitations that may have affected results of Study IV, the APA program effectiveness, its generalizability and consequently its feasibility.

First, approximately two-thirds of the vineyard-workers declined to join the intervention group. In line with the existing literature (Kelly et al. 2016; Robroek et al. 2009), the main reasons provided were the lack of interest for the APA program, the scheduling of the APA training sessions out of working hours and to perceive oneself as already physically active enough. This information is valuable since, in a certain way, they reflect a potential mismatch between vineyard-workers non participants' needs, expectations, or preferences and the APA program design. Since no guidelines exist in the literature, it seems difficult to provide a valid framework to counteract the lack of interest for the APA program. Therefore, to encourage the first participation in a further APA program, it could be interesting to (1) continue to involve/invite non participants at end-of-program meetings focusing on the effects of the APA program on outcomes, (2) to complete the APA program with the implementation of educational classes (Robroek et al. 2009) and finally (3) to implement the APA program as a long-term strategy to improve non participants' perception of company commitment (Ryde et al. 2013).
Secondly, even if free of charge for employees, implementing a part of the APA program out of the working hours reduced the chances of reaching a larger participation rate (Jørgensen et al. 2016; Robroek et al. 2009; Rojatz, Merchant, and Nitsch 2016; Ryde et al. 2013). However, this choice was motivated by the specific context of the wine-producing companies, in concertation with all employees, taking in consideration the concept of shared responsibility described by Robroek and colleagues (2012) and finally in view of making this APA program sustainable.

c) Conclusions

Study IV confirmed the feasibility and effectiveness of the worksite supervised APA program among a larger sample of vineyard-workers reported in Study III. Then, Study IV determined a set of ‘ideal’ circumstances under which the implementation process increased the program effectiveness. To summarize, these ideal circumstances encompassed at least a well-established health culture in the company, a strong involvement of all employees (from top managers to front-line workers) and a close collaboration between all involved promoting shared decisions making. Then, it also included adapting the program to the workplace context, to the workers and to the working activities they carry out. The latter finding confirms that the APA program must be delivered by well-trained instructors who have a solid background in sports science, health and psychology.

GENERAL CONCLUSION AND PERSPECTIVES

This PhD thesis provides promising results for the implementation of workplace supervised APA program for vineyard-workers to increase neuromuscular capacities and to limit the aggravation of pain. Of note, these promising results stemmed from the field work exposure analysis that allowed adapting the program to the workplaces, to the workers and to the working task. However, it is noteworthy that this PhD thesis presents the findings of two programs lasting a maximum of 10 weeks and therefore cannot reveal long-term effects of such intervention. In this sense, the APA program implemented in this PhD thesis does not target one of the main challenges of WMSD prevention which relies on the implementation of long-term and sustainable programs. For this reason, future studies among vineyard-workers should focus on the implementation of APA programs with longer duration and should particularly pay attention to the program compliance which can be negatively affected over time (Mortensen et al. 2014). For researchers, this necessarily involves questioning and quantifying exposure to risk factors during the remaining activities performed over a working year such as attaching and trellissing vines, leaf removal, crop-thinning, etc. Then, when promising results are observed on neuromuscular capacities such as trunk muscle endurance and flexibility or on pain relief, it may not be surprising to observe positive effects on other outcomes such as absences for sick leave, presenteeism, productivity and health care utilization. However, the latter finding reinforces the idea that worksite supervised APA programs should be implemented within multi-year strategic planning and over a longer duration since effects on these outcomes are commonly observed after two or three years (Goetzel et al. 2014). In this sense, the two participating wine-producing companies presented in this PhD thesis chose to continue the APA program. Therefore, future studies should assess whether these wine-producing companies will be able to maintain the positive effects reported earlier on neuromuscular capacities, low back pain relief and training adherence. Then, the sustainability of the program largely depends on the employers' and employees willingness to support and adhere to such a program (Jakobsen et al. 2015). Of note, from the employers' perspective, it is important to know the costs and whether this program can lead to an acceptable financial return on investment. Therefore, based on an increasing body of literature on this topic (Berger et al. 2001; Bergström et al. 2009; Goetzel et al. 2014; Strijk et al. 2011), future studies among vineyard-workers should investigate whether the implementation of worksite supervised APA program are cost-effective. From the employees' point of view, personal incentive including improved physical capacity and social interactions at work are important. Finally, as mentioned earlier the commitment of several stakeholders is a pre-requisite for the sustainability of the program. Interestingly, these promising results have already made it possible to obtain the support of the social partners which enabling the continuation and the development of future ergonomics interventions and APA programs.

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APPENDICES

APPENDIX 1. PAPER 1

Balaguier R, Madeleine P, Hlavackova, P, Rose-Dulcina K, Diot B and Vuillerme N. (2014) Ergonomic evaluation of pruning activity among the Chateau Larose-Trintaudon vine-workers. Proceedings of the 11th International Symposium on Human Factors in Organisational Design & Management and the 46th Annual Nordic Ergonomics Society Conference (ODAM-NES 2014).IEA Press. 965-970, 2014.

Self-reported pain and trunk posture during pruning activity among vineyard workers at the Château Larose-Trintaudon

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Abstract

This paper presents the first stage of our project aiming at preventing work-related musculoskeletal disorders and improving work conditions for the Château Larose-Trintaudon (Saint-Laurent Médoc, France) vineyard workers: an ergonomic assessment of vine pruning activity was conducted. Self-reported musculoskeletal pain increased throughout the working day in the lower back region. Furthermore, video analysis during real working conditions revealed that pruning activity exposed vineyard workers to a high risk of developing WMSD. The vineyard workers frequently adopted trunk-thigh postures considered ‘extreme’. The present ergonomic evaluation strongly suggests that back pain is an important health issue among the vineyard worker population.

Keywords. Vineyard worker; grapevine pruning activity; work-related musculoskeletal disorders; self-reported localized musculoskeletal pain assessment; video analysis.

Introduction

According to the French National Health Insurance annual report published in 2010, there were 658 000 episodes of absence from work for sick leave in France. A majority of all the days off for illness was due to work-related musculoskeletal disorders (WMSD). In its 2005-09 Health and Security Plan at work, the "Mutuelle Sociale Agricole" (MSA - French agricultural mutual insurance system) reported that WMSD counted for more than 95% of sick leave. Among all the farming sectors, viticulture is the top sector affected by WMSD. The Château Larose-Trintaudon, St Laurent-Medoc (France) is the largest vineyard in the Médoc with approximately 225 hectares. It produces more than one million bottles of wine per year and is one of the main employers of vineyard workers in the Médoc area (30 permanent vineyard workers). Despite a will to improve the working conditions by e.g., adapting work shifts, weekly equipment maintenance and professional training for the workers, the Château Larose-Trintaudon is still facing an increasing number of absences for sick leave among its vineyard worker employees (Table 1). Furthermore, most of the workers' complaints identified during the 2010-2012 period occurred during winter work and, more specifically, during the grapevine pruning activity.

Table 1. Number and percentage of working days lost due to sickness per year for the Larose-Trintaudon vineyard workers between 2010 and 2012.

Years	Number of working days per year	Number of working days lost due to sickness per year	Percentage of working days lost due to sickness per year
2010	7650	723	9.4
2011	7590	995	13.1
2012	7590	1325	17.4

Within this context, taking the high prevalence of WMSD especially in the vineyard workers' lower-back region during vineyard work, we were encouraged to perform an ergonomic assessment during the pruning season.

This paper presents the first stage of an intervention aiming at preventing WMSD and improving work conditions for the Château Larose-Trintaudon vineyard workers.

Our aim was to collect and analyze (1) self-reported musculoskeletal pain ratings among vineyard workers during a working week of pruning activity and (2) video recording of the grapevine pruning activity.

Methods

Study sample

Study participants consisted of a sample of 11 vineyard workers employed at the Chateau Larose-Trintaudon, St Laurent-Medoc, France. Table 2 presents the characteristics of the 11 participants who voluntarily participated in the present study.

Table 2. Characteristics of the vineyard workers, means (SD).

Characteristics	N=11
Men	6
Women	5
Age (years)	45.4 (6.3)
Height (cm)	166.6 (6.1)
Body mass (kg)	72.2 (12.4)
BMI (kg/m^2)	25.9 (3.2)
Vineyard experience	18.7 (6.6)

All 11 participants gave their informed written consent to the experimental procedure as required by the Helsinki declaration. In addition, all the collected data were managed by the MedSafe technology by the IDS Company (Montceau-les-Mines, France). IDS is an approved hosting provider in personal health data by the French Ministry for Social Affairs and Health.

Self-reported musculoskeletal pain ratings

The vineyard workers were instructed to indicate their pain ratings in 22 anatomical regions of the body on an adapted body map using a 0-10 numeric pain rating scale (0: 'No pain'; 10: 'Worst possible pain'), twice a day (before the start and after the end of the working day of grapevine pruning) during five consecutive working days of grapevine pruning (from Monday to Friday) at the beginning of January, 2014.

The 22 anatomical regions were selected using a modified French version of the standardized Nordic Questionnaire (Kuorinka et al., 1987): neck, lower back, right and left shoulders, right and left elbows, right and left wrists, right and left triceps, right and left forearms, right and left thighs, right and left knees, right and left ankles, right and left calves, right and left heels.

Video-based analysis of the grapevine pruning activity

The 11 vineyard workers were video recorded *in situ* in the Château Larose-Trintaudon vineyard during 12 minutes of pruning activity. The pruning activity consists in selecting two branches from the grapevine, which will bear grapes. In order to select these 2 branches, the vineyard workers have to bend their trunk over and then cut all the others branches using manual or electric shears.

In the present study (based on the prevalence of WMSD in vineyard workers at the Château Larose-Trintaudon vineyard and on the results from the self-reported musculoskeletal pain rating assessment), we focused on the biomechanical assessment of the lower back region. More precisely, we assessed trunk-thigh angle during the performance of pruning activity. To do so, the observer first recorded the pruning activity perpendicularly to the vineyard worker. Video analysis started at the moment when the vineyard worker cut the first branch. Using the

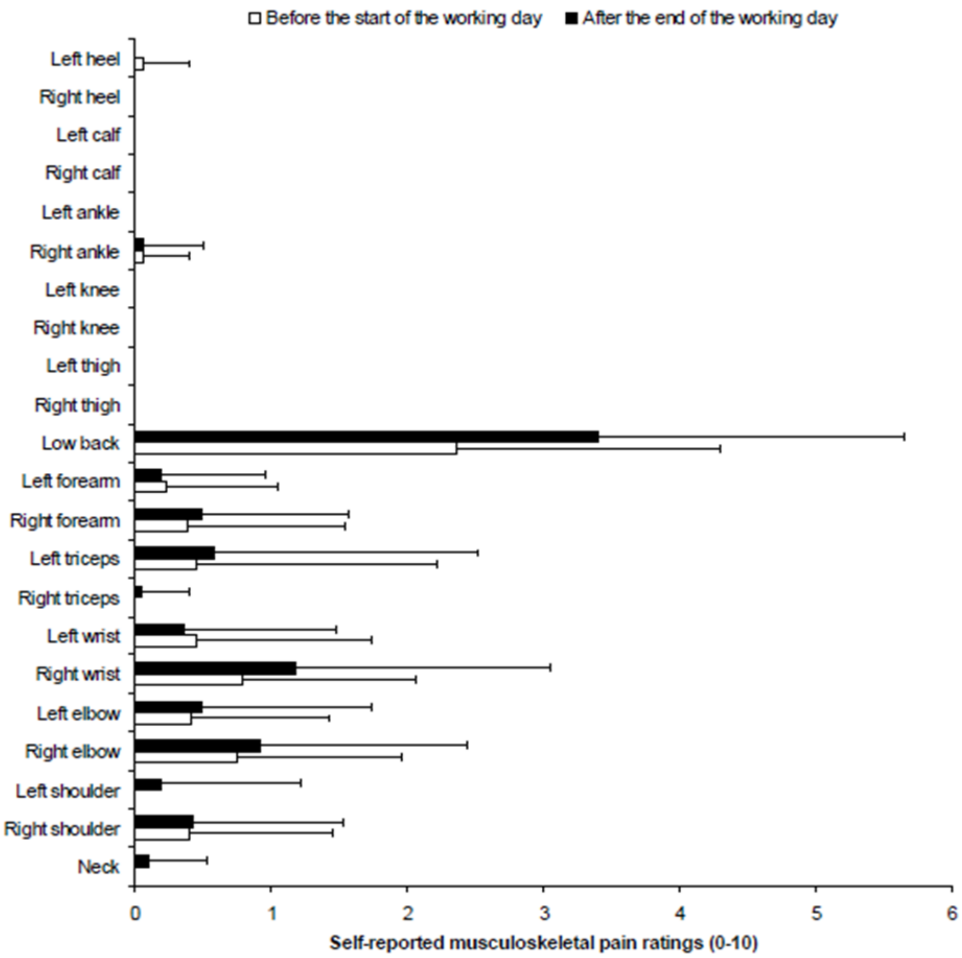
Kinovea software (http://www.kinovea.org/), on each video, we placed 3 notable anatomic markers on each vineyard worker, (1) shoulder, (2) pelvis and (3) knee (Figure 1). For each video, we were then able to calculate trunk-thigh angles and the time the vineyard workers maintained trunk-thigh angle in the following 10 intervals : Inferior to 90°, [91°-100°], [99°-110°], [111°-120°], [121°-130°], [131°-140°], [141°-150°], [151°-160°], [161°-170°] and [171°-180°]).

Results

Self-reported musculoskeletal pain ratings

The statistical analysis detected two significant main effects: Period ($F(1,10)=8.52$, $P<0.05$) and Anatomical region ($F(21,210)=8.23$, $P<0.0001$), as well as a significant two-way interaction Period × Anatomical region ($F(21,210)=4.06$, $P<0.0001$).
Figure 2 illustrates this two-way interaction and presents the mean + SD of the self-reported musculoskeletal pain ratings obtained before the start and at the end of the working day of grapevine pruning obtained for each of the 22 anatomical regions.

Figure 2. Mean + SD of the self-reported musculoskeletal pain ratings before the start of the working day of grapevine pruning and at the end of the working day of grapevine pruning obtained for the 22 anatomical regions.

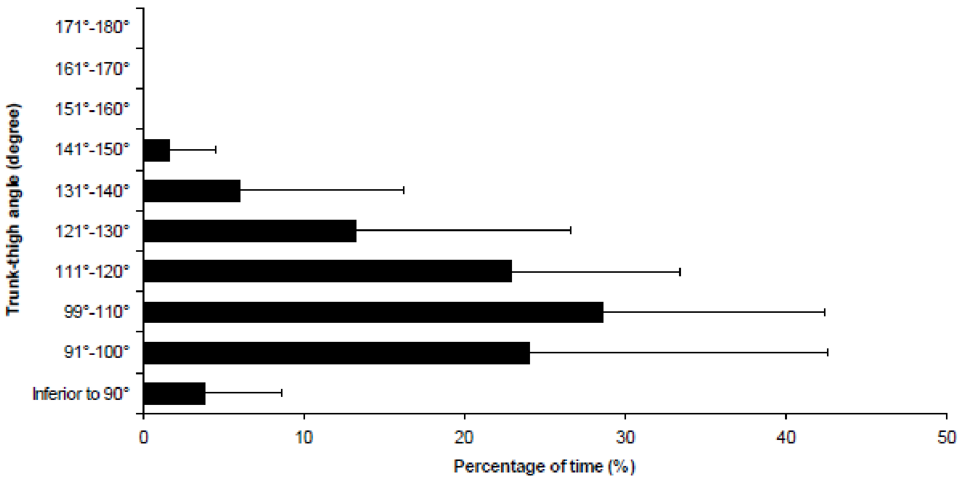


The decomposition of this two-way interaction into its simple main effects indicated significantly higher pain rating in the lower back region compared with the other anatomical regions (P<0.0001). Furthermore, the pain rating in the lower back region was significantly higher at the end of the working day compared with the start of the working day of grapevine pruning (P<0.0001).

Video analysis of trunk-thigh angle during grapevine pruning

Figure 3 presents the percentages + SD of work time spent by the vineyard workers in the 10 trunk-thigh angles intervals during a 12-min grapevine pruning activity.

Figure 3. Mean + SD of the percentages the winegrowers spent in different Trunk-Thigh angles intervals during the 12-min grapevine pruning activity.



The statistical analysis showed a significant main effect of trunk-thigh angle interval ($F(9,90)=13.8$, P<0.0001). The post-hoc analysis further indicated that the percentages of pruning working time spent with the trunk-thigh angles comprised in the three intervals of [91°-100°], [99°-110°], and [111°-120°] were significantly larger than those spent in the seven other intervals (P<0.05).

The descriptive analysis further showed that the vineyard workers never maintained a trunk-thigh angle greater than 150° during the grapevine pruning activity. The vineyard workers spent 100% of their working time with trunk-thigh angle less than 150° and 79% of their working time with trunk-thigh angle less than 120°.

Discussion and Conclusion

The results of the self-reported pain ratings indicated that the most painful region among vineyard workers was the lower back area (Figure 1). Our observation is in accordance with two recent studies that have concluded that the back is the anatomical region with the highest prevalence of musculoskeletal pain in vineyard workers (Bernard et al. 2011; Brumitt et al. 2011). More originally, our results further revealed that self-reported pain from the lower back significantly increased throughout the working day of vine pruning. This suggests that the pruning task *per se* could increase the risk of chronic or recurrent musculoskeletal lower back disorders in vineyard workers. Meyers et al. (2004) have indicated that the most prominent risk factors for back injury in vineyard work include repetitive lifting/carrying of heavy loads, repetitive exertion of force by the trunk and upper extremities, tractor driving and more notably repetitive or sustained awkward postures of the trunk.

Considering the biomechanical characteristics of the pruning task, we carried out a 2D kinematic analysis of vineyard workers performing daily pruning work to estimate the biomechanical exposure of the back. The present field study was conducted in real working conditions. Thus, the work organization (e.g. piece-rate), incentive schemes and the physical environment of the work place (e.g. temperature, humidity and tool quality) were considered. The present study presents some limitations in terms of its duration and size of the population investigated. However, this study provides new genuine information related to the biomechanics of vine pruning. The kinematic analysis showed that the vineyard workers spent 100% of their working time with a trunk-thigh angle less than 150° and 79% of their working time with a trunk-thigh angle less than 120° (Figure 3) during grapevine pruning. These results suggest that the pruning activity is associated with a high risk of developing WMSD in the lower back. The adoption of frequent and continuous trunk-thigh postures can be considered as ‘extreme’. These analyzes suggest a link between the pain ratings in the lower back and the postural constraints associated with this task (Bernard et al. 2011). As such, the reported complaints are closely linked to the adopted posture at work (Madeleine and Madsen, 2009). Moreover, the kinematics data can be used in a participatory ergonomic approach (Hanse and Forsman, 2001) to provide the workers with interactive information about awkward postures. Thanks to this field ergonomic evaluation among vineyard workers at the Château Larose-Trintaudon during the vine pruning activity, the AGIM Univ. Grenoble-Alpes members in close collaboration with the Center for Sensory-Motor Interaction (SMI) at Aalborg University are now developing a project based on a physical activity program aiming at reducing pain in the lower back region and preventing WMSD among vineyard workers.

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APPENDIX 2. PAPER 2

Balaguier R, Madeleine P, Rose-Dulcina K, Vuillerme N. Trunk kinematics and low back pain during pruning among vineyard workers-A field study at the Chateau Larose-Trintaudon. PloS One. 2017;12(4):e0175126.

TRUNK KINEMATICS AND LOW BACK PAIN DURING PRUNING AMONG VINEYARD WORKERS – A FIELD STUDY AT THE CHATEAU LAROSE-TRINTAUDON

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Abbreviation:

Body mass index: BMI ; Low back pain: LBP ; Pressure pain thresholds: PPT ; Work related musculoskeletal disorders: WMSDs

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Abstract

The prevalence of low back disorders is dramatically high in viticulture. Field measurements that objectively quantify work exposure can provide information on the relationship between the adopted trunk postures and low back pain. The purposes of the present study were three-fold (1) to carry out a kinematics analysis of vineyard-workers' pruning activity by extracting the duration of bending and rotation of the trunk, (2) to question separately the relationship between the duration of forward bending or trunk rotation with low back pain intensity and pressure pain sensitivity and (3) to question the relationship between the combined duration of forward bending and trunk rotation on low back pain intensity and pressure pain sensitivity. Fifteen vineyard-workers were asked to perform pruning activity for 12 minutes with a wireless triaxial accelerometer placed on their trunk. Kinematic analysis of the trunk showed that vineyard-workers spent more than 50% of the time with the trunk flexed greater than 30° and more than 20% with the trunk rotated greater than 10°. These results show that pruning activity lead to the adoption of forward bent and rotated trunk postures that could significantly increase the risk of work related musculoskeletal disorders in the low back. However, this result was mitigated by the observation of an absence of significant association between the duration of forward bending and trunk rotation with low back pain intensity or pressure pain sensitivity. Even if prospective field measurements and studies assessing the effects of low back pain confounders are needed, this field study provides new genuine information on trunk kinematics during pruning activity.

Key-words: Agriculture ; work related musculoskeletal disorders ; three dimensional trunk motion ; low back pain.

Introduction

Work related musculoskeletal disorders (WMSDs) affecting the low back are considered in numerous industrialized and developed countries as a major public health problem [1-4]. For instance, Farioli and colleagues [5] have recently reported a 46% one year prevalence for low back pain (LBP) among almost 35 000 European workers. The consequences of LBP include disability, early retirement, healthcare consumption, loss of productivity and sickness absences [6,7]. Among all the working sectors, the highest rate of LBP is commonly observed in agriculture [5]. Thereby, in a recent review on the prevalence of WMSDs among farmers, Osborne and colleagues [8] have reported respectively a 75% lifetime and a 48% one year prevalence of LBP. In France, the viticulture sector, which employs more than 500 000 persons, is the agricultural sector with the highest prevalence of WMSDs in the low back [9,10]. Although the origin of LBP is multifactorial, biomechanical risk factors such as heavy physical workload, repetitive motions, awkward postures - especially excessive forward bending and rotation of the trunk - are known to increase the risk of new and recurrent episodes of LBP [11-17]. Interestingly, the few studies assessing WMSDs risk factors among vineyard-workers have also reported an exposure to these biomechanical risk factors especially during the winter job activities such as fixing and pruning [9,18-21]. In an epidemiological study among almost 4 000 French vineyard-workers, Bernard and colleagues [9] have concluded that the postural constraints during pruning activity could increase the risk of LBP. Meyers and colleagues [18], using an observational checklist, have reported that the risk of LBP was increased during pruning due to frequent trunk flexion up to 90°. However, biomechanical exposure in these afore-mentioned studies have been assessed using self-reported measurements or observational methods which can tend to overestimate the time of exposure to risk factors [22-24]. Kato and colleagues [21] have conducted an experimental study addressing the effects of different pruning trellis systems on the risk of developing WMSDs in the lower back. However, a single field study has to our knowledge assessed trunk postures among vineyard-workers during pruning [25]. At this point, this study presents two major limitations. First, it was focused on the assessment of trunk thigh angle in the sagittal plane, while numerous studies have highlighted the effect of the duration of trunk forward bending and trunk rotation on the risk of LBP [26-28]. Second, it did not assess the association between physical exposure and risk of LBP among vineyard-workers, while numerous studies have highlighted the need to evaluate more precisely this association using objective and quantitative field measurements [16,29,30]. As mentioned in numerous studies [31,32], one valid approach to quantify the risk of LBP among workers is to assess the relationship between duration of forward bending and self-reported LBP intensity, e.g. using numeric pain rating scale (NRS). Such analysis can be complemented by measurements of pressure pain thresholds over the low back. Consequently, assessing pressure pain sensitivity over locations of the low back offers an interesting and reliable [33,34] opportunity to investigate and visualize the associations of trunk forward bending, trunk rotation and pain sensitivity.

The purposes of this field study were three-fold:

(1) to carry out a kinematics analysis of vineyard-workers' pruning activity by extracting the duration of forward bending and rotation of the trunk, that is two factors that are recognized to predispose to low back disorders [16,26-28,35];

(2) to assess separately the relationship between the duration of forward bending or trunk rotation on LBP intensity and pressure pain sensitivity ; and

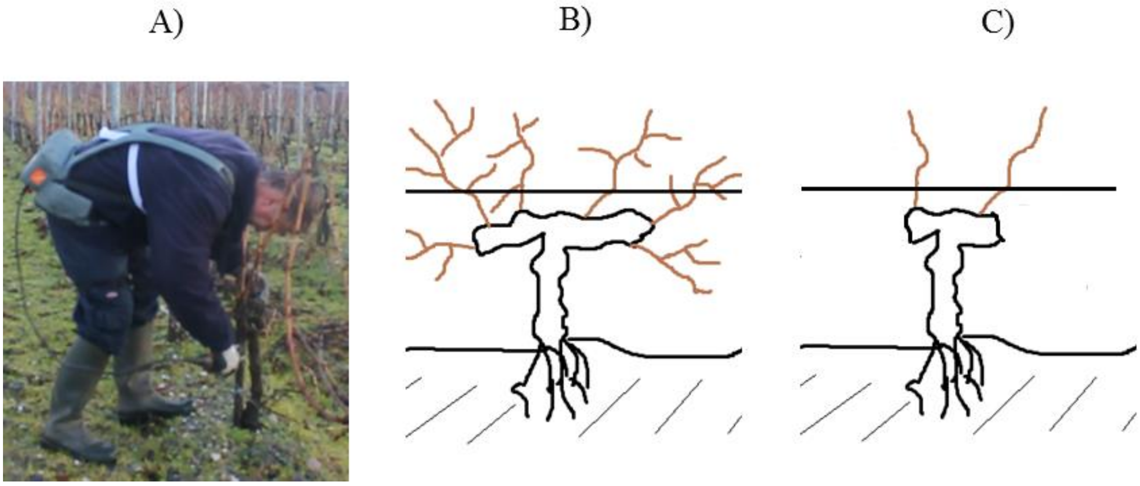
(3) to question the relationship between the combined duration of trunk forward bending and trunk rotation with LBP intensity and pressure pain sensitivity.

Material and methods

Description of pruning activity

In France, pruning activity generally occurs over 5 months (from November to March). This activity aims at controlling the vine's development to avoid the production of branches at the expense of grapes. To limit the growth of the vine cep, vineyard workers have to cut precisely some branches, approx. between 25 and 50 cuts per minute [20] with a pruning shear to finally keep 2 main branches that will bear the grapes (Figures 1A, 1B and 1C). At Château Larose-Trintaudon (France), this activity is generally performed both by men and women.

Figure 1. Common postures adopted by vineyard-worker posture during pruning (A). Cep vine before (B) and after pruning (C).



Participants

Fifteen out of the 24 vineyard-workers employed by the Chateau Larose-Trintaudon (France) volunteered to participate in the study. Table 1 shows the characteristics of these participants. The study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all vineyard-workers included in this study. The participants gave their written informed consent (as outlined in PLOS consent form) to publish these case details. In addition, all the collected data were managed by the MedSafe technology by the IDS Company (Montceau-les-Mines, France). IDS is an approved hosting provider in personal health data by the French Ministry for Social Affairs and Health. Some of the results have been briefly presented during the 6th annual meeting of the Danish Biomechanical Society.

Table 1. Characteristics of the vineyard-workers. Mean (SD)

Variables	Women (n=6)	Men (n=9)
Age (years)	48.8 (4.1)	43.0 (7.6)
Height (cm)	163.2 (4.8)	171.7 (7.0)
Body mass (kg)	68.5 (13.9)	78.7 (14.3)
BMI (kg/m²)	25.6 (4.0)	26.5 (3.2)
Job seniority (years)	20.5 (3.6)	17.6 (8.0)
Right-handed (n)	5	9
Left-handed (n)	1	0

Data collection

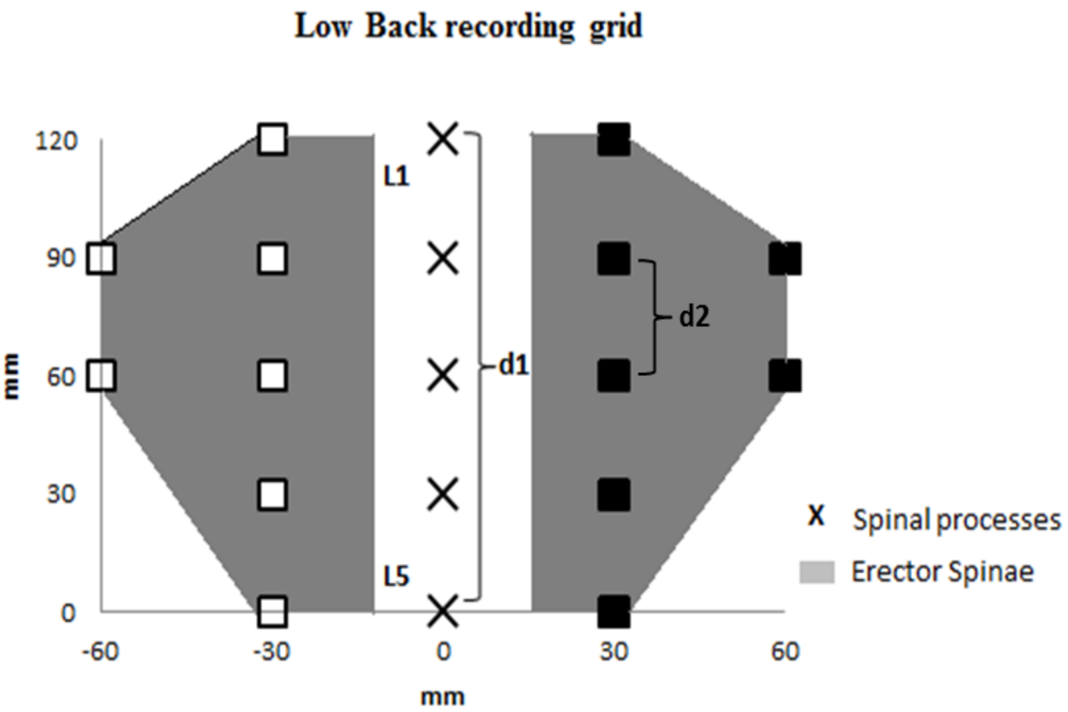
Data was collected over 8 weeks from January to March 2014. Trunk kinematic was recorded using one wireless inertial measurement unit combining a 3D angular gyroscope, a 3D accelerometer and a 3D magnetometer (I4 motion, Technoconcept, Mane, France ; sampling frequency : 100 Hz) and fixed with an adjustable elastic belt to the chest of the participants at the level of the sternum [36]. This location was preferred to the back area often chosen to monitor trunk movement [32,37,38] insofar the vineyard-workers usually carry a harness with a battery placed in this body region. Then, vineyard-workers were asked to perform pruning activity for a period of 12 minutes [25].

Low back pain intensity and pressure pain sensitivity

A numeric rating scale was used to assess pain intensity of the low back region over the two weeks prior to the data collection. Vineyard-workers were asked to rate their pain intensity using a 0-10 numeric rating scale (0:"No pain", 10: "Worst imaginable pain") [25,31] every working day over the 2 weeks prior data collection. The mean of these ratings was used for data analysis enabling to assess the relationship between trunk kinematics and the pain intensity representing a proxy of the pain commonly reported in the low back region by the participants from the Chateau Larose-Trintaudon.

Pressure pain sensitivity of the lower back region was assessed by measuring PPT over 14 anatomical locations in the low back region (Figure 2) of the vineyard-workers [33,34]. For the analysis, the 7 anatomical locations placed to the left side of the spinal processes have been grouped as P_{left}, the 7 anatomical locations placed to the right side of the spinal processes have been grouped as P_{right} and the 14 locations placed to the left of the spinal processes have been grouped as P_{all}. For that purpose, a handheld electronic algometer (Somedic, Algometer Type 2, Sollentuna, Sweden) with a 1cm² wide rubber tip was used. The examiner measured PPT a constant slope of 30 kPa/s, three times on each anatomical location. The mean of three PPT measurements of all 14 locations was used for data analysis [33,34,39]. PPT were collected during one session lasting approx. 30 minutes in the 2 weeks prior to the data collection.

Figure 2. Schematic representation of the low back pressure pain threshold recording grid of the left (blank square) and right (black squares) erector spinae muscles. d1 represents the distance between the first (L1) and the fifth (L5) lumbar vertebrae. d2 equals one fourth of d1.



Statistical analyses

Trunk flexion and trunk rotation were categorized from cut-off angles commonly used in the literature. On the one hand, the selected trunk forward bending cut-off angles were the following : <30°, >30°,>60° and >90° [16,26,31,32,40,41] (Figure 3). On the other hand, the selected trunk rotation cut-off angles were the following: <10°, >10° and >30° [27,28] (Figure 4). Percentage of time spent in each cut-off angle was calculated. As data did not follow a normal distribution, Mann-Whitney or Wilcoxon tests were performed to compare the percentage of time spent in each cut-off angle.
Furthermore, Spearman rank correlation coefficient was used to assess the strength and the direction of the association between pressure pain sensitivity or LBP intensity and the time spent in each cut-off angle separately for trunk forward bending and trunk rotation. Then, a sensitivity analysis using a median split to equally separate into 2 groups our sample of vineyard-workers [33,34,42,43] was performed for all cut-off angle to assess whether LBP intensity or pressure pain sensitivity was different between vineyard-workers below or above the median split . Finally, scatter plots were generated to assess the relationship between the combined duration of forward bending and trunk rotation with LBP intensity and pressure pain sensitivity. *P*-values <0.05 were considered statistically significant. All data analyses were performed with R 3.0.1 software (R foundation for Statistical Computing, 2013, Vienna, Austria). Results are presented as median, 25th and 75th percentiles, unless otherwise indicated.

Figure 3. Graphical representation of cut-off angles (i.e. >30°, >60° and >90°) for trunk forward bending.

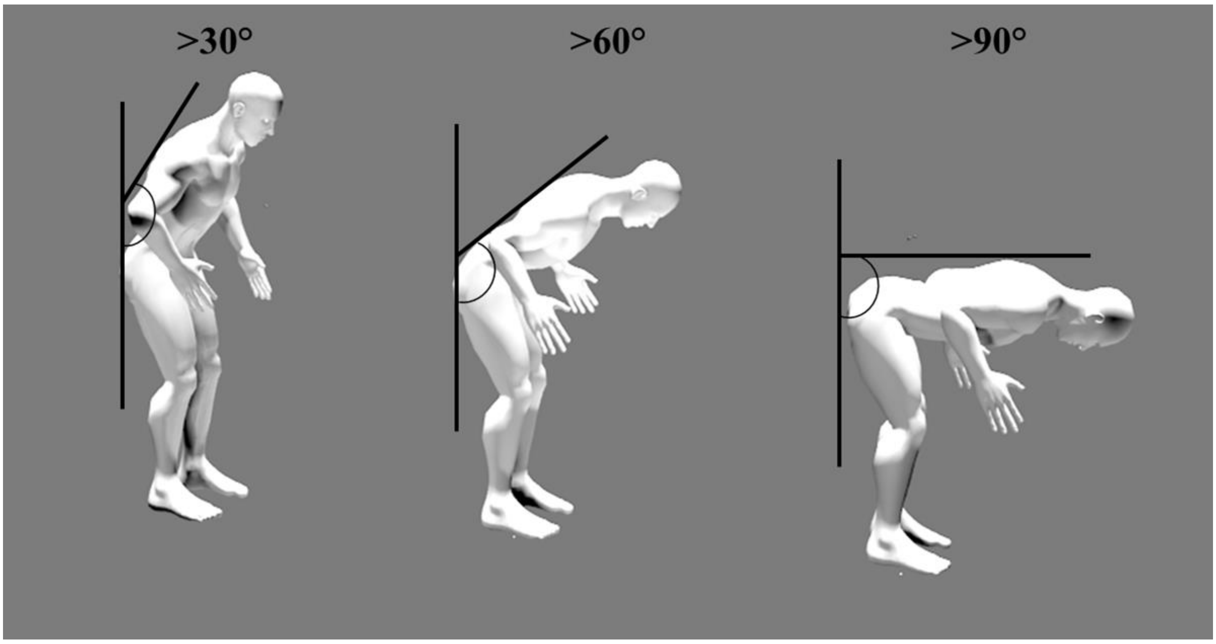
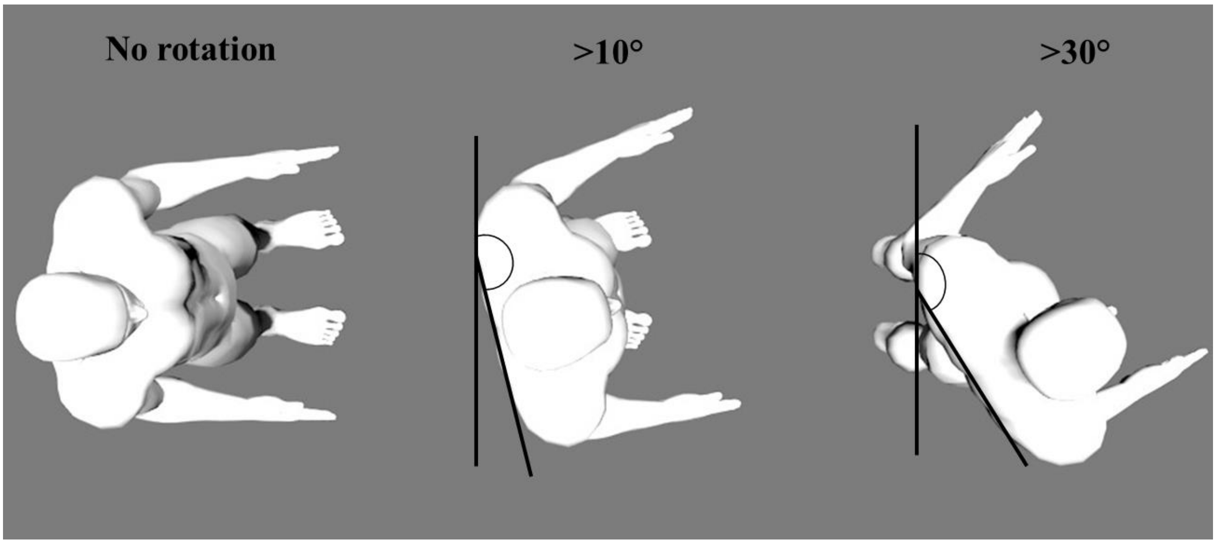


Figure 4. Graphical representation of cut-off angles (i.e. >10° and >30°) for trunk rotation



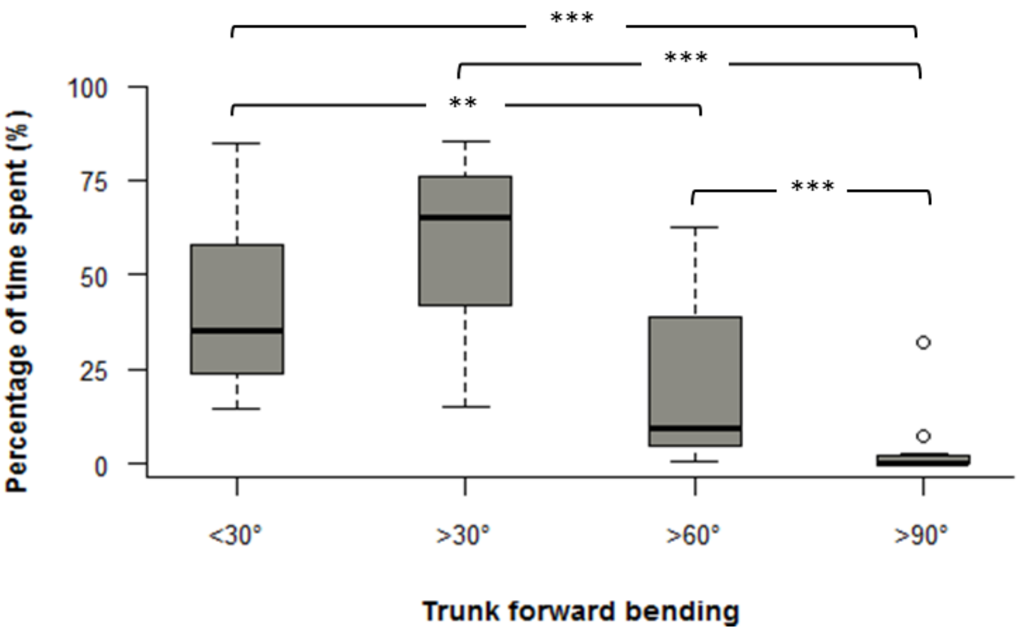
Results

Kinematic analysis of the trunk

Forward bending of the trunk

Figure 5 shows that more than 50% of time was spent with trunk bent forward >30°. Furthermore, vineyard-workers spent significantly more time with the trunk bent forward >30° compared to <30° (P<0.05).

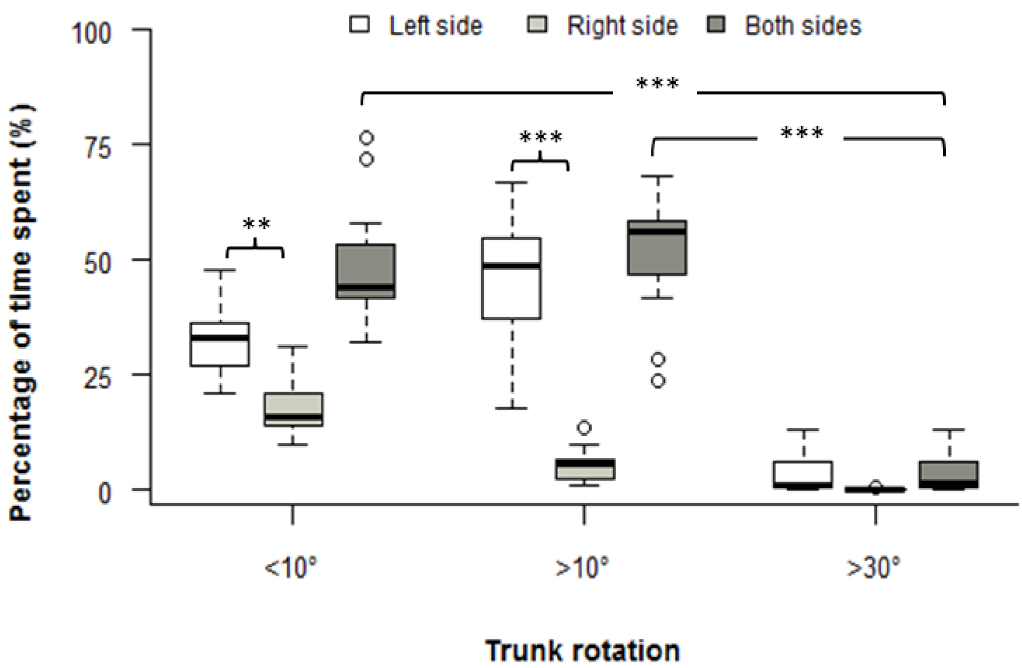
Figure 5. Pruning boxplot of the percentage of time spent at each cut-off angles for trunk forward bending *: *P* < 0.05 ; **: *P* < 0.01 ; *: *P* < 0.001**.



Rotation of the trunk

Figure 6 shows that approx. 50% of the time was spent with the trunk rotated >10°. Furthermore, vineyard-workers spent significantly more time with the trunk rotated on the left side compared with the right side for all the cut-off angles excepted for >30° (*P*<0.05).

Figure 6. Pruning boxplot of the percentage of time spent at each cut-off angles for trunk rotation *: *P* < 0.05 ; **: *P* < 0.01 ; *: *P* < 0.001.**



Relationship between duration of forward bending or rotation of the trunk with LBP intensity and pressure pain sensitivity

No significant correlation (Spearman rank coefficient) between the duration of forward bending of the trunk and LBP intensity or PPT was found significant. The Spearman rank correlation coefficients ranged from -0.2717 to 0.2824 and from -0.1376 to 0.1376 between duration of trunk rotation and PPT or NRS (Table 2).
The time spent with the trunk bent forward or rotated following a median split for PPT, LBP intensity was similar to the ones obtained for the entire population (Table 3). Furthermore, there were no significant difference between PPT values measured on the left side (PPT_{left}) and the right side (PPT_{right}) of the low back (Table 4).

Table 2. Correlation coefficient (rho-Spearman) calculated for pressure pain thresholds (PPT, kPa) and low back pain (LBP, 0-10 scale) intensity for trunk flexion and trunk rotation cut-off angles.

		PPT (kPa)		LBP intensity (0-10)	
	Angles	**r**	**p-value**	**r**	**p-value**
Trunk forward bending	**<30°**	0.1464	0.6024	-0.2717	0.3273
	>30°	-0.1464	0.6024	0.2717	0.3273
	>60°	-0.1571	0.5756	0.2824	0.3078
	>90°	0.1784	0.5247	-0.0821	0.7713
Trunk rotation	**<10°**	-0.1286	0.6482	-0.1376	0.6248
	>10°	0.1286	0.6482	0.1376	0.6248
	>30°	0.1321	0.6389	0.1180	0.6754

Table 3. Pressure pain thresholds (PPT, kPa) and low back pain intensity (LBP, 0-10 scale) using median split and 25th, median 75th according to cut-off angles for trunk flexion (<30°, >60°, >90°) and trunk rotation (>10°, >30°).

			PPT (kPa)			LBP intensity (0-10)		
	Angles	**Median**	**25th**	**Median**	**75th**	**25th**	**Median**	**75th**
Trunk forward bending	>30°	<69.1%	307.9	471.9	614.9	1.6	2.6	2.7
		>69.1%	224.7	294.8	453.7	2.8	3.6	5.1
	>60°	<9.2%	307.9	471.9	614.9	1.6	2.6	2.7
		>9.2%	287.6	346.7	436.7	2.8	3.6	5.1
	>90°	<0.1%	233.6	341.6	608.6	1.6	2.7	2.8
		>0.1%	287.6	346.7	453.7	2.8	3.6	5.1
Trunk rotation	>10°	<46.6%	181.0	280.5	469.9	2.1	3.2	4.6
		>46.6%	318.2	452.2	608.6	2.0	2.7	2.8
	>30°	<0.3%	236.8	452.2	546.5	2.0	2.6	3.0
		>0.3%	318.2	346.7	463.5	2.2	2.8	5.1

Table 4. Pressure pain thresholds (kPa), 25th, median and 75th for the 14 locations covering the low back region.

Points	25th	Median	75th
P_{left}	373.4	558.0	740.3
P_{right}	389.1	568.3	747.7
P_{all}	381.3	563.1	744.0

Combined associations of the duration of forward bending and rotation of the trunk with LBP intensity or pressure pain sensitivity

No significant association between the combined duration of forward bending and flexion of the trunk with LBP intensity or PPT was found (Figures 7 and 8).

Figure 7. Scatter plots of the correlation between the different cut-off angles for trunk forward bending (>30°, >60°, >90°), trunk rotation (>10°, >30°) and low back pain intensity (LBP, 0-10).

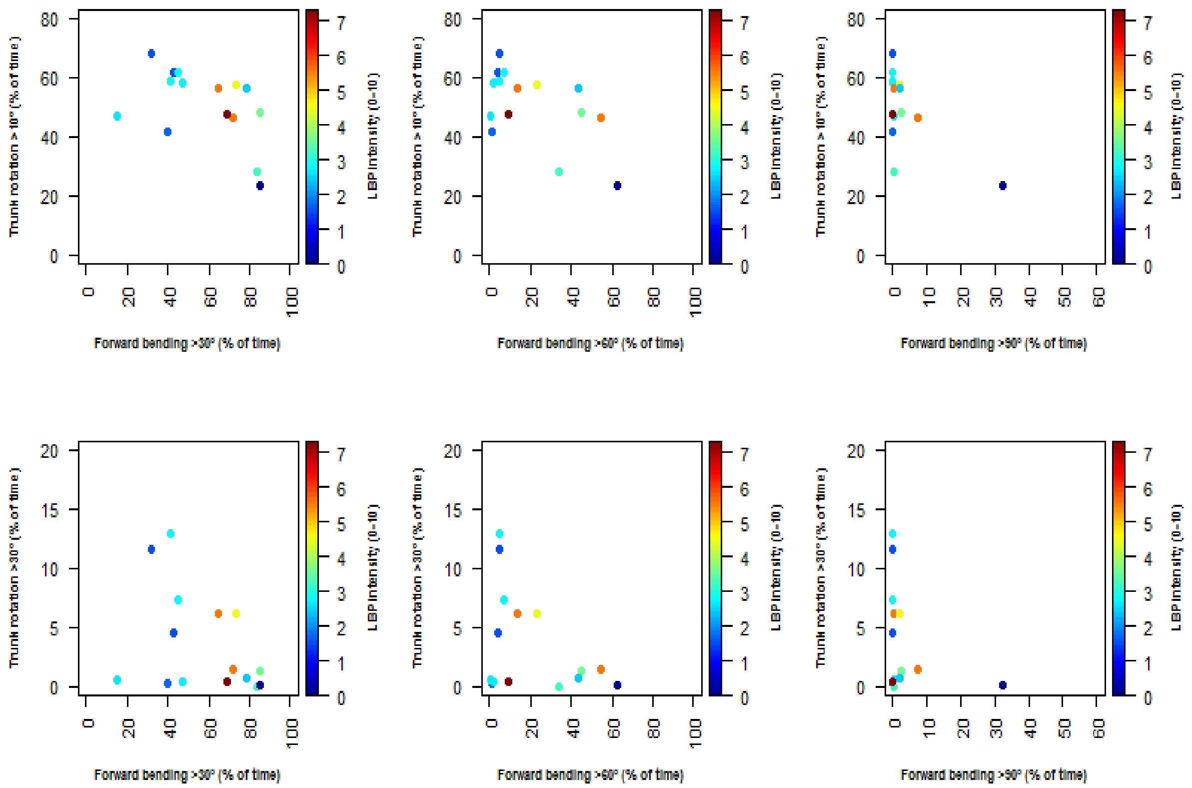
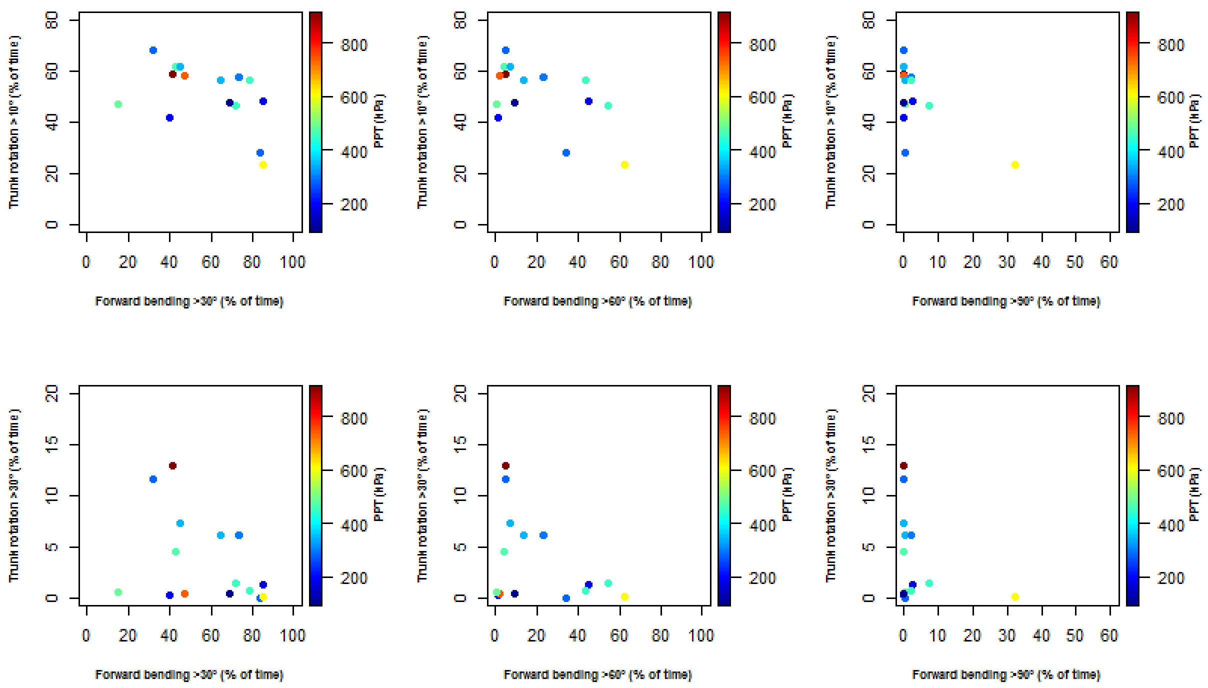


Figure 8. Scatter plots of the correlation between the different cut-off angles for trunk forward bending (>30°, >60°, >90°), trunk rotation (>10°, >30°) and pressure pain thresholds (PPT, kPa).



Discussion

Taken together, the present findings showed that vineyard-workers' pruning activity is likely to lead to the adoption of bent and rotated postures for relatively long period of time. For instance, during the 12 minutes of pruning activity, vineyard-workers spent almost 60% of the time with the trunk bent forward >30°. Our results are comparable to those reported in a study specifically designed to assess the effects of different pruning trellis on the risk of WMSDs in the low back [18]. In the latter, 11 vineyard workers were asked to perform a simulated pruning task during approx. five minutes showing that vineyard-workers spend between 31% and 80% with the trunk bent forward > 30°. Once extrapolated over a working day, this result suggests that vineyard-workers spend most of their working time with trunk postures which have extensively been reported to increase the risk of LBP [15,27,28]. Interestingly, Coenen and colleagues [26] have reported that this risk is significantly amplified when the trunk is bent >60° more than 5% of the time. In our study, pruning activity largely exceeded this threshold (i.e., 21%), consequently increasing the risk of LBP among vineyard-workers. This observation is corroborated by previous studies showing that trunk forward bending negatively affects viscoelastic tissues such as ligaments, fascia, discs [44-46] and spine stability. Indeed, prolonged trunk forward bending increases the risk of ligaments laxity and ligaments micro-damages, the risk of inflammation and, consequently, the risk of LBP [44,46].

However, the Spearman rank analysis and the sensitivity analysis using a median split showed no significant relationship between the time spent in each cut-off angles for both trunk forward bending and trunk rotation with LBP intensity and pressure pain sensitivity. In other words, our results suggest no association between the duration and the angulation of trunk forward bending or trunk rotation with LBP intensity or pressure pain sensitivity. This finding is in line with recent studies questioning this relationship [16,31,32,47]. For instance, Villumsen and colleagues [32,47] have reported a negative association between the time spent with the trunk bent forward and LBP intensity in a cohort of blue-collar workers. In another study, Lagersted-Olsen and colleagues [31] questioning the relationship between the duration of forward bending and LBP over a year period have also concluded that the risk of developing or aggravating LBP is not directly associated with the duration of forward bending at work when using angles >30°, >60° and >90°.

Thus, we assess trunk rotation and we can argue that pruning activity can be considered as a task that combined trunk forward bending and trunk rotation. For instance, vineyard workers spent 50% of the 12 minutes working time with the trunk rotated >10° for pruning. Similar rotated trunk postures have been previously observed among other workers such as sheep shearers [48] or paramedics [49]. However, during the 12 minutes of pruning activity, vineyard-workers spent significantly most of the time with the trunk rotated to the left side for all cut-off angles (i.e. <10°, >10° and >30°). This result clearly suggests a trunk asymmetry between the left and right side during the performance of this task. This observation could be explained by the vineyard-workers handedness which determines whether the vineyard-worker stand on the right or left side of the vine and could explained why the pattern observed for the left-handed vineyard-worker is not different from the right-handed. Similar to longer time spent in bent postures, trunk rotation is also reported to increase lower back muscle activation and decrease ligaments laxity [50]. During a symmetric flexion task, loads are shared equitably between both sides of the spine [51,52]. However, during an asymmetric flexion task, Ning and colleagues [53] have observed on the contralateral side of the rotation an increasing tension in spine ligaments and on the ipsilateral side a longer muscle activation finally increasing the risk of LBP [26]. However, this longer muscle activation does not result in decreased PPT on the low back muscles of the ipsi or contra-lateral side of the rotation. Indeed, our results revealed no significant difference between PPT values of the left and right side of the low back confirming, for the sample size of 15 vineyard-workers, the absence of association between trunk rotation and pain sensitivity mentioned earlier.

Avoiding bent or rotated trunk postures may result in lower mechanical exposure and could consequently be considered among others as one of the main reasons given to the lack of association between high LBP intensity and time spent with the trunk forward bent or the trunk rotated [32,54]. However, in our study this explanation seems unlikely as the duration of forward bending >30° once extrapolated on a working day (i.e. almost 252 min/day) is twice higher than that reported by Villumsen and colleagues [32], i.e. 100min/day among blue-collar workers. Results of the present study could also be attributable to at least two other factors: (1) a “floor effect” as the median low back pain intensity reported by vineyard-workers is relatively low, i.e. around 3 on a 0-10 rating scale [55]; and (2) the fact that the most in pain vineyard-workers may have left the profession making our vineyard-workers “healthy survivors”. This latter explanation seems particularly relevant as our sample of vineyard-workers have seniority close to 20 years. Finally, a third possible explanation recently argued by Lagersted-Olsen and colleagues [31] is that assessing separately the effect of forward bending or trunk rotation on LBP intensity can lead to miss a possible association between these outcomes. At this point and as recently suggested by Lagersted-Olsen and colleagues [31], we have assessed the combined effect of duration of forward bending and trunk rotation on LBP intensity and PPT. Our results show no significant association

regarding all the possible combinations between trunk forward bending, trunk rotation cut-off angles and mean LBP intensity over the last two weeks of work or PPT. In other words, LBP intensity or pressure pain sensitivity was not affected by the combined effects of duration of forward bending and trunk rotation. However, further studies assessing this relationship among a larger sample of vineyard-workers are needed to complete our results.
This study presents several limitations. First, the rather small sample size of 15 vineyard-workers from a single castle may limit the generalizability of the results to all vineyard-workers. However, we believe that this was sufficient to generate relevant results. Indeed, it is important to mention that the number of vineyard-workers that volunteered to participate in this study represented more than 65% of the entire vineyard-workers population of the Château Larose-Trintaudon. Further, this Château is the largest vineyard in this area with almost 500 acres of vineyard and more than 1 million of bottles produced each year. Second, the method used for the kinematics analysis of vineyard-workers' pruning activity is also not without limitations. Third, measuring trunk kinematics using a single wireless inertial measurement unit combining a 3D angular gyroscope, a 3D accelerometer and a 3D magnetometer during a fast paced activity such as pruning may have resulted in measurement error. Further, the relative short duration of the recordings (12 minutes) questions the reliability of the data. Indeed, previous studies have assessed physical exposure at work over an entire or several working days [26-28,46,56,57]. At this point, however, it is conceivable that the nature of the professional task (e.g., variety, repetitiveness…) is an important factor that should influence the appropriate duration and frequency of recordings. Hence, unlike the above mentioned studies assessing a wide range of physical exposure among numerous working sectors such as metal, chemical, food and wood sectors [26-28,56], pruning task is considered highly repetitive and rather monotonous [18,20]. That is the reason why we are confident to consider a 12 minutes recording as sufficient to compute reliable kinematic data and to obtain a realistic picture of the adopted postures during pruning. Of note, Kato and colleagues [18] have asked 11 vineyard-workers to perform pruning during 5 minutes to assess the effects of different pruning trellis on trunk postures, whereas Roquelaure and colleagues [20] have analyzed pruning activity of six vineyard-workers for approximately 8 minutes to conclude that pruning activity lead to the adoption of extreme wrist postures. Fifth, it is noteworthy that the presence of examiners during the performance of pruning activity may have changed vineyard-workers working habits. In this sense, the exposure to bent or rotated postures should have been underestimated [48]. After all and even if PPT measurements do present advantages like the link with musculoskeletal pain and its semi-objective character [58-60], PPT cannot be considered as a substitution tool for objective diagnoses of LBP. However, the sensitivity analysis performed in this study and the high percentage of non-specific LBP reported among the entire population (i.e. almost 90%) [61] lead us thinking that our results were not affected by the absence of objective diagnosis. Despite these limitations, the present study assessing vineyard-workers activities is the necessary first step before developing and implementing adapted interventions [62]. Still prospective studies are needed to determine the effects of work exposure on LBP. Finally, we have also conducted analyses to assess the effect potential well known LBP confounders such as gender, age, weight and BMI [9,63] on trunk kinematics and risk of LBP. Although our analyses revealed that women spent significantly more time with the trunk flexed >60° and that age, weight and BMI did not change LBP intensity and PPT values, our small sample size prevents us from being able to generalize our findings.

Conclusions

This field study revealed that vineyard-workers adopt bent forward and rotated trunk postures that may increase the risk of WMSDs in the low back during the execution of pruning activity. Indeed, more than half of the assessed working time was spent with the trunk flexed greater than 30° and more than 20% with the trunk rotated greater than 10°. Then, our study has also pointed out a significant difference between left and right rotation of the trunk. However, our study did not reveal any relationship between duration of forward bending or trunk rotation and LBP intensity or pressure pain sensitivity. Finally, this study reinforces the necessity of further field measurements with longer time of observation and larger sample size to confirm our findings and to investigate other variables specifically the effects of potential LBP confounders such as gender, age or job seniority to accurately quantify the risk exposure

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APPENDIX 3. PAPER 3

Balaguier R, Madeleine P, Rose-Dulcina K and Vuillerme N. Effects of a worksite Supervised adapted physical activity program on trunk muscle endurance, flexibility and pain sensitivity among vineyard workers. J Agromedicine. 2017; 22(3):200-214.

Effects of a worksite supervised adapted physical activity program on trunk muscle endurance, flexibility and pain sensitivity among vineyard workers. Proof of concept

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Abstract

In viticulture, the prevalence of low back pain is particularly high among vineyard workers exposed to sustained and awkward postures. One promising setting for low back pain prevention resides in the implementation of workplace physical activity. This non-randomized pilot study aims at evaluating the effects of a worksite supervised adapted physical activity program among seventeen vineyard-workers volunteered to enter either an intervention group (n=10) or a control group (n=7).The intervention group followed a physical activity program for 8 weeks involving (1) 15 minutes of warm-up every working day and (2) two weekly one hour of adapted physical activity sessions targeting trunk muscle endurance and flexibility. The control group was advised to continue normal physical activity. Evaluations were carried out at week 0, week 4, week 8 and week 12. Physical capacity was assessed using flexibility tests for the trunk, along with trunk muscle flexor and extensor endurance tests. Finally, pain sensitivity was evaluated by assessing pressure pain thresholds over 14 anatomical locations in the low back region. For the intervention group, the endurance of the trunk extensor and flexor significantly increased from baseline to week 8 as well as the pressure pain thresholds. No change was observed for the control group over the same period. Our encouraging results in combination with the high adherence rate set interesting foundations for the promotion of worksite supervised adapted physical activity and most likely, offer a new promising approach to prevent low back pain among vineyard-workers.

Keywords: Adapted physical activity, Work, Low back pain, Pressure pain threshold, Agriculture.

Abbreviations

ANOVA	Analysis of variance
APA	Adapted physical activity
ES	Effect size
FTF	Finger to floor
LBP	Low back pain
LSB	Left side bending
PPT	Pressure pain threshold
RCT	Randomized Controlled Trial
RSB	Right side bending
SR	Sit and reach
WHO	World Health Organization
WMSDs	Work related musculoskeletal disorders

Introduction

World wine production was around two hundred and seventy million hectolitres in 2014[1]. Seventeen per cent of the world's wine is produced in France resulting in the employment of more than 500,000 persons[2]. In France, this sector of agriculture also reports the highest prevalence of work related musculoskeletal disorders (WMSDs)[3]. Bernard et al[4] have conducted an epidemiologic study among 4000 French vineyard-workers and reported that WMSDs primarily affect the low back. The number of WMSDs is also reported to be higher during winter when pruning occurs. The risk of developing WMSDs in the low back region during pruning activity partially stems from the adoption of frequent and sustained awkward posture[5,6]. This phenomenon also concerns all agricultural sectors around the world[7,8,9,10]. For instance, 29% of the agricultural workers in the United States of America suffered from WMSDs, mostly located in the low back[11]. Moreover, Brumitt et al[12] have noted that almost half of the vineyard workers in the United States of America report low back pain (LBP). The imbalance between work exposure and physical capacities is a reason put forward to explain the risk of WMSDs among workers exposed to physically heavy work[13-15] such as vineyard-workers. Moreover, prospective studies have highlighted that workers with low trunk muscle endurance and flexibility are more prone to WMSDs in their low back[16,17]. Consequently, one promising way to increase physical capacity resides in the implementation of an appropriated training program targeting muscle endurance and flexibility[18,19]. For several years now, the workplace appears to be a prime setting to implement such a program since it offers employees the opportunity to make healthy choices and therefore potentially limit their risk exposure and prevent the development of work related musculoskeletal pain [20-22]. Moreover, the implementation of a worksite adapted physical activity (APA) program aiming at improving the level of physical capacity seems to be a suitable approach that could remove the barrier to practice physical activity not directly related to work activities[21]. This supposition is corroborated by the increasing body of literature reporting positive effects of a worksite APA program and particularly the effects of supervised program[23- 27] on musculoskeletal pain[28,29]. Therefore, the quantitative assessment/evaluation of this musculoskeletal pain over an APA program remains important if not essential. Interestingly, pressure algometry offers this possibility since the method is commonly used by clinicians and researchers to assess pain sensitivity of deep structures as well as the effects of an intervention[30- 35]. The assessment of pressure pain threshold (PPT) has been suggested as a surrogate for musculoskeletal injuries[34,36] and lower PPT have been previously reported among workers suffering from WMSDs[36-38]. Moreover, this semi-objective method appears to be particularly sensitive to benchmark mechanical pain hyperalgesia [39-42]. Further, a decrease in pain sensitivity has recently been reported by Cho and colleagues[22] over the low back area after a physical activity program suggesting that PPT may be a useful outcome to measure the effects of such a program on LBP. However, to the best of our knowledge, no study has investigated the effects of a worksite supervised APA program targeting trunk muscle endurance and flexibility among vineyard workers. We hypothesized that an APA program would result in increased endurance and flexibility of the trunk as well as decreased musculoskeletal pain sensitivity in the low back region. A prospective study involving an intervention group and a control group was specifically designed to address this issue.

Methods

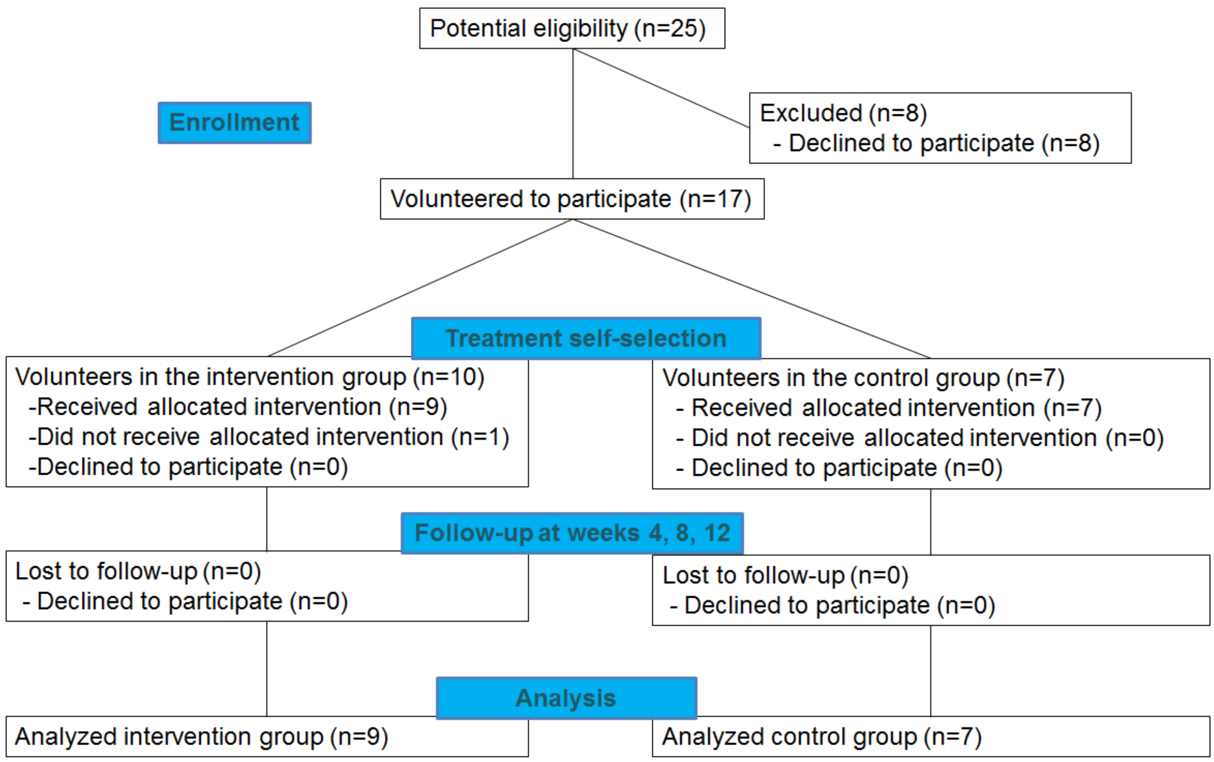
Participants

Among the 25 vineyard-workers employed at the Chateau Larose-Trintaudon (France), 17 volunteered to participate in the study. To participate in the study the inclusion criteria were being aged between 18-55 years, no previous surgery in the low back region in the last 12 months, working full time and having at least 1 year of employment in the company. Vineyard-workers that volunteered to participate in the APA program were included in the intervention group (N=10), while the remaining workers were allocated to the control group (N=7) (Figure 1). This non-randomized control study design was chosen after discussion with the vineyard-workers and the Direction of the Château Larose-Trintaudon to encourage informed shared decision making[27]. The Château Larose-Trintaudon is the largest vineyard in the area of Bordeaux (France). For several years, it has developed a label called "Vignoble Responsable ®[b]" aiming at promoting sustainable development and improving employees' well-being. Then, under the label "Vignoble Responsable ®" and from an ethical point of view in a company[43], it was impossible to a priori exclude voluntary vineyard-workers from the intervention group. Finally, this experimental design was implemented to increase adherence to the intervention[44]. All the participants completed a questionnaire assessing demographic characteristics such as age, gender, educational level, number of working hours, seniority and LBP intensity. The baseline characteristics of the participants are presented in Table 1. The study was conducted in agreement with the Declaration of Helsinki. Written informed consent was obtained from all participants included in this prospective study. In addition, all the collected data were managed by the MedSafe technology by the IDS Company (Montceau-les-Mines, France). IDS is an approved hosting provider of personal health data by the French Ministry for Social Affairs and Health.

Adapted Physical Activity Intervention

The APA program was carried out at the Chateau Larose-Trintaudon over an eight-week period from January to March 2014. All the participants of the intervention group were invited to follow a supervised 15 minutes warm-up, at the beginning of every working day (i.e., 5 days a week). This warm-up consisted of various static and dynamic exercises aiming at mobilizing muscles and joints particularly stressed during the working day, i.e. trunk muscle and joints, legs, shoulders. As soon as possible after warming-up, participants were asked to start their daily work activities. Then, participants were asked to follow 2 weekly one hour supervised APA sessions after the end of the working day. These sessions were organized as follows: approximately 40 minutes of trunk flexor and extensor strengthening and 20 minutes of trunk stretching. Dynamic and static exercises have been implemented using several materials such as gym-balls, medicine balls, elastic bands and weights. These exercises have been previously used in studies targeting WMSDs affecting the low back[45-47] and consisted in abdominal crunch with and without swiss-ball[46-48], ventral sheathing[30,47,48], lateral sheathing[30,47,49,50]. The APA sessions took place in a room located at the workplace. Participants were free to choose two time slots per week among the 4 available (i.e. from 5.00 pm to 6.00 pm from Monday to Thursday), with the constraint that there was a maximum of 7 participants per session. The program was also individualized in terms of workload meaning that when one of the participants was unable to achieve an exercise, the examiner adapted the exercise accordingly. The participants were tested on 4 successive occasions: (1) at baseline (week 0), (2) in the middle of the APA program (week 4), (3) at the end of the APA program (week 8) and (4) four weeks after the end of the intervention (week 12). After March vineyard workers change their activities passing from pruning to lopping, lifting, palling and driving tractors. For instance, palling which consists in rising a tightened wire throughout a vineyard rank, is a more demanding upper body task. Consequently, vineyard-workers used different tools and are exposed to different biomechanical risk factors[51]. In conclusion, the period of APA cessation (i.e. from week 8 to week 12) was chosen to ensure no major changes among vineyard-workers activities and to study post-intervention effects.

Figure 1. Flowchart of participants' recruitment.



Adherence and outcome assessment

The APA program was conceived and supervised by two trained and educated examiners (RB and KRD). The APA examiners noted the presence of the participants after each APA session. Adherence was defined as the number of APA sessions performed with respect to the total number of sessions initially planned (i.e., 16, two sessions per week during 8 consecutive weeks). Finally, the APA examiners were also in charge of the outcome measurements and consequently were not blinded to group status.

Table 1: Baseline characteristics of the vineyard-workers (mean (standard deviation))

	Control (N=7)	Intervention (N=9)	Total (N=16)	p-value
Women	1	5	6	
Age (years)	44.7 (6.7)	45.7 (8.0)	45.1 (7.0)	NS
Height (cm)	165.8 (5.9)	171.4 (7.6)	168.3 (7.1)	NS
Body mass (kg)	72.0 (13.2)	78.8 (14.5)	74.9 (13.8)	NS
BMI (kg/m^2)	29.7 (4.5)	25.8 (4.9)	27.8 (4.7)	NS
Seniority (years)	18.3 (7.6)	19.3 (6.0)	18.8 (6.7)	NS
LBP intensity (last 7 days)	2.9 (1.0)	4.1 (2.3)	3.5 (1.6)	NS

BMI: Body mass index; LBP: low-back pain; NS: Non significant

Outcome Measures

Trunk muscle flexibility

The Finger to floor (FTF) test is appropriate, valid and reliable to assess changes in trunk flexibility after a rehabilitation or a physical activity program[52,53]. For this test, the vineyard-workers were standing on a 43 cm high box with the feet placed parallel and 10 cm apart. Then, participants were asked to bend forward as far as possible while keeping the knees straight. The distance (cm) between the floor and the middle finger was recorded as an index of trunk forward bending flexibility[54,55].

Trunk lateral flexibility using the side bending test was also measured as described by Frost et al[56]. Participants were asked to tilt their trunk on the right and left side as far as possible. The distance (cm) between the floor and the middle finger was recorded to assess trunk side-bending flexibility.

The sit and reach (SR) test was used to assess the hamstrings flexibility[57]. Participants were sitting on the floor in front of a specially designed box with their heels against the box, their legs totally extended and their upper body straight. Then, the examiner asked the participants to push forward as far as possible a sliding device placed on the top of the box. The distance was registered in cm and the point 0 was placed at 23 cm from the participants' heels[58].

Three trials with one minute of rest were performed for all the flexibility tests and the best performance was extracted for statistical analyses[59].

Trunk muscle endurance

Trunk extensor and flexor endurance times were assessed with tests specifically used in the management of LBP patients[60,61].

For the assessment of trunk extensor endurance time, participants were asked to lie on an examination table with the iliac crests perpendicular to the table edges. Then, participants with the lower limbs fixed to the table and the arms folded under the chest were instructed to hold the trunk in a horizontal position for no longer than 240 seconds[60,62,63]. For this test, excellent reliability has previously been reported by Latimer et al[64].

For the assessment of trunk flexor endurance time, participants were required to sit on the floor with their knees flexed to 90° and the feet held by the examiner. Participants inclined their trunk at 60° against a wedge placed behind them. At the beginning of the test, vineyard-workers were asked to recover the trunk in order not to be in contact with the wedge, to keep their arms across their chest and to maintain this position for no longer than 300 seconds[65-67]. Excellent reliability has also been previously reported for this test[66]. To ensure recovery between trunk muscle flexor and endurance tests, 5 minutes of rest was granted to the participants[66].

Pressure Pain Thresholds over the lower back region

PPT were assessed by a single examiner over 14 anatomical locations on both sides of the lumbar spinal processes L1-L5 with a pressure algometer (Type 2, Somedic, Sollentuna, Sweden). Participants were lying in a prone position. Pressure was applied perpendicularly to the skin at a rate of 30 kPa/s with a skin contact area of 1 cm². Participants were instructed to press the stop button of the algometer when pressure changed to pain. After familiarization, three PPT measurements were made on each of the 14 anatomical locations with 1 minute interval between two consecutive measurements. The approach has recently been reported to be valid and reliable among asymptomatic subjects and vineyard-workers[68,69]. The mean of the three measurements were used for data analysis[70,71]. Finally, PPT maps of the 14 anatomical locations were generated (Figure 2) as described in recent studies by Binderup et al[72,73].

Adverse events

The participants were asked to report any adverse events such as discomfort or pain caused by the APA program.

Statistical analyses

Using an intention to treat analysis[30,34], a two-way repeated measure analysis of variance (RM-ANOVA) with the Holm-Šídák test for pairwise comparison and that controls for multiple comparisons was used for (1) all the outcome measures at baseline and (2) for changes from week 0 to week 4, week 0 to week 8, week 0 to week 12. Groups (control and intervention) and sessions (weeks 0, 4, 8 and 12) were used as independent factors of the RM-ANOVA. Finally, the mean PPT value of the 14 anatomical locations was used for data analysis[68,69]. The significance level was set at $P<0.05$. Results are expressed as mean (95% confidence interval [CI])[30,34].

The present study can be seen as a pilot study and our objective was to enroll all the workers from the Château Larose Trintaudon. Therefore, power calculations were performed a posteriori. The effect size (ES) and power[74] were computed for (1) baseline measurements and (2) mean differences from baseline to the three follow-ups sessions.

Results

Adherence

Eight workers (approx. 32%) of out the 25 did not wish to participate. Seventeen volunteered to participate (Figure 1). Due to personal reasons, one participant from the intervention group decided to quit the APA program before the first session. During the 8 weeks of the APA program, the nine vineyard-workers of the intervention group all achieved the 16 initially planned sessions, resulting in 100% adherence. No participants reported adverse events due to the APA program.

Outcome Measures

At baseline no statistically significant differences were observed between the control group and the intervention group, except for PPT. At baseline, effect sizes were 0.8, 0.9, 0.1, 0.5, 0.4 and 0.4 for FTF, SR, lateral flexibility on the right and left side, for the trunk extensor and flexor endurance time, respectively. In parallel, values calculated for power were 0.9, 0.9, 0.1, 0.4, 0.3 and 0.4.

Trunk muscle endurance and flexibility

The trunk muscle endurance time and flexibility results at week 0, 4, 8 and 12 are presented in Table 2.

The intervention group had significantly larger changes than the control group (1) for the extensor endurance test from week 0 to week 8, (2) for the flexor endurance test and the finger to floor from week 0 to week 4, from week 0 to week 8, from week 0 to week 12, and (3) for the right side bending test from week 0 to week 4 (Table 3).

Pressure pain thresholds

The PPT mean difference was significantly larger for the intervention group compared with the control group from week 0 to week 8 and from week 0 to week 12 (Figure 2).

Table 2: Mean (95% Confidence Interval) for all the endurance and flexibility outcomes measures according to the two groups (Control and Intervention) and the four sessions (weeks 0, 4, 8 and 12).

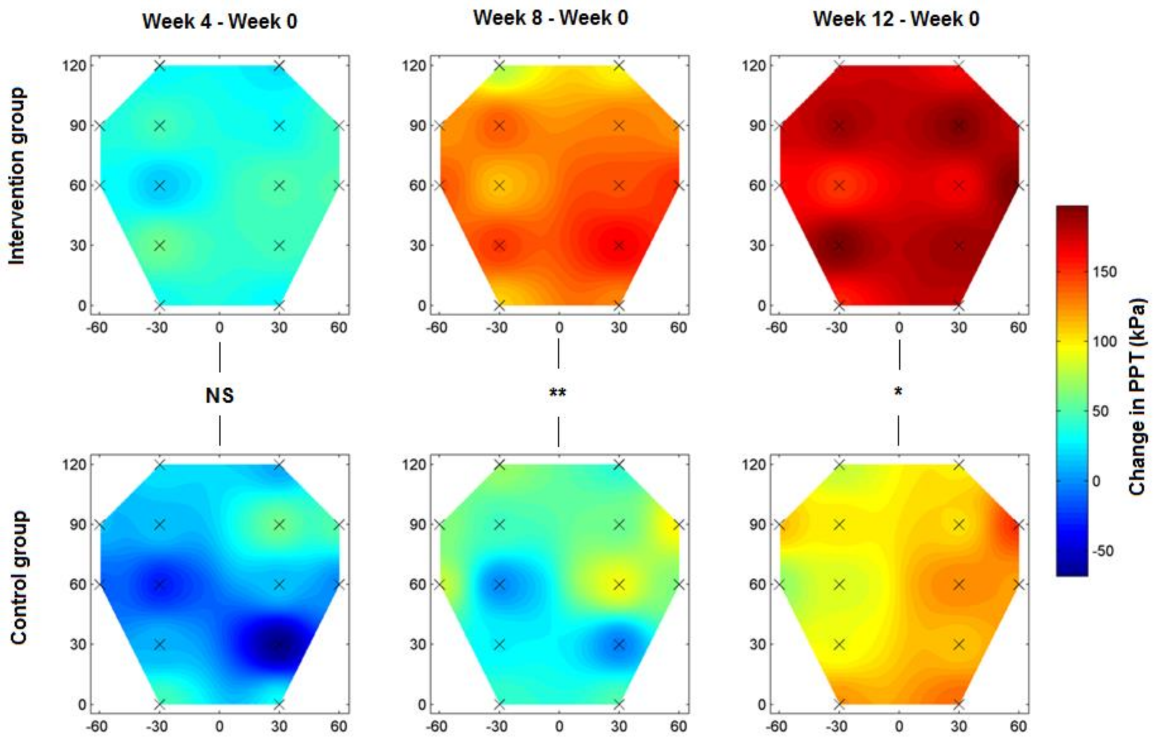
	Week 0		Week 4		Week 8		Week 12	
Outcomes	**Control**	**Intervention**	**Control**	**Intervention**	**Control**	**Intervention**	**Control**	**Intervention**
Finger to floor (cm)	47.6 (42.5 - 52.6)	38.7 (34.5 - 42.9)	47.4 (43.3 - 51.4)	32.4 (29.5 - 35.2)	48.3 (43.7 - 52.8)	32.7 (30.6 - 34.8)	48.9 (43.7 - 54.1)	34.9 (32.2 - 37.5)
Sit and reach (cm)	22.5 (19.5 - 25.5)	29.0 (25.6 - 32.5)	25.0 (22.3 - 27.7)	33.9 (30.8 - 37.1)	24.7 (22.1 - 27.3)	34.9 (33.1 - 36.6)	24.1 (21.0 - 27.2)	33.6 (31.5 - 35.7)
Right side bending (cm)	83.5 (80.3 - 86.7)	83.2 (82.1 - 84.3)	85.8 (84.1 - 87.5)	80.0 (78.7 - 81.3)	86.3 (84.6 - 88.0)	81.1 (80.3 - 81.9)	85.4 (82.9 - 87.8)	83.1 (82.4 - 83.7)
Left side bending (cm)	86.1 (81.8 - 90.3)	83.3 (81.8 - 84.7)	87.5 (85.5 - 89.5)	81.9 (80.8 - 83.0)	87.2 (85.2 - 89.2)	81.9 (80.8 - 83.0)	86.6 (83.9 - 89.2)	83.4 (82.5 - 84.4)
Trunk extensor endurance (sec)	68.8 (48.3 - 89.4)	53.7 (38.5 - 68.9)	68.3 (40.7 - 95.8)	90.6 (65.1 - 116.0)	73.6 (46.4 - 100.8)	121.7 (92.0 - 151.4)	71.7 (37.6 - 105.7)	108.2 (83.5 - 133.0)
Trunk flexor endurance (sec)	92.1 (54.0 - 130.1)	64.1 (39.3 - 88.9)	104.6 (59.2 - 150.0)	138.2 (98.3 - 178.1)	116.1 (68.0 - 164.2)	206.0 (168.8 - 243.2)	127.8 (7.8 - 184.8)	190.6 (141.5 - 239.7)
Pressure pain threshold (kPa)	496.7 (375.1 - 618.3)	284.0 (217.7 - 350.2)	508.1 (384.8 - 631.4)	321.0 (232.7 - 409.3)	548.8 (435.0 - 662.7)	411.6 (294.7 - 528.6)	568.1 (451.6 - 684.6)	432.4 (314.4 - 550.5)

Table 3: Mean difference (95% Confidence Interval) from baseline (week 0) to follow-ups three sessions (week 4, 8 and 12) for all the trunk muscle endurance and flexibility outcomes measures according to the two groups (Control and Intervention).

	Week 4 – Week 0				Week 8 – Week 0				Week 12 – Week 0			
Outcomes	**Control**	**Intervention**	**ES**	**power**	**Control**	**Intervention**	**ES**	**power**	**Control**	**Intervention**	**ES**	**power**
Finger to floor (cm)	-0.2 (-2.2 - 1.78)	-6.3** (-8.0 - -4.6)	1.6	1.0	0.7 (-0.8 - 2.3)	-6.0*** (-8.5 - -3.5)	1.6	1.0	1.4 (-0.7 - 3.5)	-3.8* (-6.2 - 1.4)	1.1	0.9
Sit and reach (cm)	2.5 (1.3 - 3.6)	4.9 (3.4 - 6.5)	0.9	0.9	2.2 (0.7 - 3.7)	5.9 (3.6 - 8.1)	1.0	0.9	1.5 (-0.1 - 3.2)	4.6 (2.4 - 6.8)	0.8	0.8
Right side bending (cm)	2.3 (0.2 - 4.4)	-3.2** (-4.7 - -1.8)	1.6	1.0	2.8 (0.8 - 4.7)	-2.1* (-3.1 - -1.1)	1.5	1.0	1.9 (-0.6 - 4.3)	-0.2 (-1.7 - 1.34)	0.5	0.4
Left side bending (cm)	1.4 (-1.3 - 4.2)	-1.4 (-3.3 - 0.5)	0.6	0.5	1.1 (-1.3 - 3.6)	-1.4 (-2.2 - -0.5)	0.7	0.7	0.5 (-1.8 - 2.8)	0.2 (-1.6 - 1.9)	0.1	0.1
Trunk extensor endurance (sec)	-0.5 (-20.9 - 19.8)	36.9 (24.1 - 49.6)	1.1	0.9	4.7 (-17.6 - 27.1)	68.0** (47.2 - 88.7)	1.4	1.0	6.4 (-18.6 - 31.3)	54.5 (35.0 - 74.1)	1.1	0.9
Trunk flexor endurance (sec)	12.5 (-19.3 - 44.3)	74.2* (52.7 - 95.6)	1.1	0.9	24.1 (2.3 - 45.9)	141.9*** (122.7 - 161.2)	2.8	1.0	28.8 (4.9 - 52.6)	126.4** (97.3 - 155.6)	1.8	1.0

ES: effect size ; *: P < 0.05 ; **: P < 0.01 ; ***: P < 0.001

Figure 2. Pressure pain thresholds mean difference for week 4 - week 0, week 8 - week 0 and week 12 – week 0 according to the two groups (Control and Intervention). *: P < 0.05 ; **: P < 0.01 ; ***: P < 0.001.



Discussion

The present study highlighted the effects of a worksite supervised APA program in a small population of vineyard-workers on adherence, on trunk muscle endurance, flexibility and on pain sensitivity. The encouraging results to promote APA among vineyard-workers are reinforced by the high power posteriori calculations[74] reported for all the outcomes beside lateral flexibility. For this latter, the inadequate power suggests an increased risk of type-II[74]. Firstly, 68% of the Château Larose-Trintaudon vineyard-workers volunteered to take part in the present study. Obviously, having a large adherence rate provides information on the program efficacy[44,45,75]. Interestingly, in the present study, the adherence was 100% with 16 sessions planned and carried out by the vineyard-workers. At this point, it is important to mention that results of the present study should not be dissociated from the treatment self-selection which has previously been reported as a likely driver of high adherence rates to intervention[76]. This full adherence with the APA program could be explained by the training facilities located at the workplace[77], the relatively short duration of the APA program (8 weeks) and the establishment of 4 time slots, giving to the vineyard-workers more freedom of choice[78]. Moreover, the effect of supervision should not be underestimated[29,45,50] as it seems necessary to vary and individualize the exercises[79] and consequently maintaining participants' adherence over time[45]. Since adherence during workplace physical activity programs, commonly ranged from 35% to 85%[45,75,80,81], is likely to stem from the context in which the intervention takes place[77,82,83] , it would be ambitious to expect a full adherence if such an intervention was implemented at another worksite and concerned the entire workforce. However, further studies among vineyard-workers can rely on our intervention and should also implement mixed-methods approaches[84,85] to get closer from the full adherence observed during this APA program. At baseline, the results of our study have revealed rather low trunk muscle endurance among vineyard workers compared to age-matched patients suffering from LBP[59,86]. This result was observed for the endurance time of the trunk extensor where the endurance time among vine-workers was approx. 70 seconds compared with the 100 seconds reported among coal miners with LBP[87,88] or the approx. 90 seconds reported among office-workers with LBP [64,89,90]. Conversely, trunk flexibility was found to be within the normal range for adults[91].

The worksite supervised APA program showed promising findings regarding physical capacities since it resulted in improved trunk muscle endurance and flexibility in the intervention group. For instance, the endurance and the flexibility increased substantially, 68 and 142 seconds for the trunk endurance times and around 6 centimetres for the trunk flexibility tests (bending). Interestingly, in the meantime, no significant changes have been noticed in the control group. Additionally, among healthy workers with lower than normal trunk muscle endurance (60 seconds at baseline), Sihawong et al.[92] have reported an endurance improvement of 15 seconds after a nine months physical activity program involving 2 sessions of 10 minutes per week. Another study among office-workers suffering from LBP has reported improvement of approx. 20 seconds for both trunk flexor and extensor endurance times after a nine months intervention with 5 sessions of 11 minutes per week[26]. A similar improvement of 20 seconds has also been reported among workers in the automotive industry who followed 3 sessions of 60 minutes per week over an eight-week period[46]. Finally, the improvement observed in trunk muscle endurance among the vineyard-workers in the intervention group reached over the eight-week period of the APA program has allowed them to achieve physical performances considered as “good” in the literature[60,62,86,89,93]. These findings are important considering the fact that participants with the poorest performances during the extensor endurance test (i.e. 104 - 110 seconds) are at higher risk of experiencing LBP[91] compared with participants with higher level of performance[91].

Four weeks after the end of the APA program (week 12), physical performances remained above baseline level in the intervention group and no significant change was observed between week 8 and week 12. Comparisons with the existing literature on training cessation among workers remain difficult. Indeed, training interventions, physical evaluations and populations can be very different between studies[95]. However, our observations are in line with the review by Mujika and Padilla[96] who have suggested that 4 weeks of training cessation can be insufficient to observe a change in strength endurance. Interestingly, Tucci et al.[97] have reported that, to maintain trunk endurance over time and after a ten-week training program targeting trunk muscles, the frequency of training sessions could be limited to one per month if the volume and the intensity of the training remain unchanged. In our case, it could be interesting to implement fewer training sessions per week after the end of the 8 weeks APA program.

To our knowledge, the present study was the first one assessing the effects of a worksite supervised APA program on PPT in the lower back region on vineyard-workers. Interestingly, at baseline, the intervention group was more sensitive to mechanical pain (lower PPTs) than the controls despite similar LBP intensity. Low PPTs have been previously reported as a risk for the development of WMSDs[36] and as well as a risk of long term absences for sick leave[98]. The findings of the present worksite intervention, i.e. increase in PPT after an eight-week

APA program are in line with previous studies[30,99]. In agreement with the findings on endurance time and flexibility, PPTs increased after week 8 leading to PPT levels in the low back region similar to those reported in healthy subjects[68]. The improvement observed from week 0 to week 4 could be due to measurement error considering that the minimum detectable change for PPTs in the lower back region is approx. 100 kPa[34,68,69]. However, the change in PPTs can be considered as clinically relevant at the end of the APA program (week 8) for the intervention group. Similarly, a 10 weeks physical activity program (i.e. specific neck strength training) with three 20 minutes sessions per week among office-workers with neck pain also led to approx. 120 kPa increases[30,99]. Finally, the increased PPTs seen after week 8 were clinically relevant and may contribute to decrease the risk of WMSDs and long term absences for sick leave[36,72,100]. Potential surrogates for WMSDs should be addressed in studies with longer longitudinal design. Interestingly, numerous authors have pointed out that PPTs are sensitive to work exposure and generally, pain sensitivity decreased as the exposure increased[36,98,100]. In our study, four weeks after the end of the APA program (week 12), PPTs remained similar to the levels observed at week 8. This finding should be associated with the maintenance of trunk muscle endurance and flexibility over the same period.

There are several limitations to the current study. First, the allocation to the intervention or control group was not randomized as emphasized earlier and the examiners were not blinded to group status. Detection bias is introduced when examiners are not blinded to the group assignment[101]. Numerous studies[102-105] have emphasized that unblinded examiners were prone, consciously or unconsciously to encourage participants' performance generally leading to an overestimation of the intervention effects. Following this line of thought, the large overall improvement we observed in trunk muscle endurance and flexibility in the present study may be partially explained by this detection bias. As recently pointed out by Hróbjartsson et al.[102] implementing outcome measurement blinding was certainly effective in increasing internal validity of the study but also contributes in increasing its complexity and its cost. Although successful randomized controlled trials exist for WMSDs and present the highest internal validity[30,105,107], a number of studies have recently challenged the feasibility of RCT in workplace environments[30,43,80,108,109]. Overall, these studies have indeed pointed out the difficulty, if not impossibility, (1) to blind the intervention [43,79,108,109], (2) to deal with potential participants and/or supervisors who do not accept randomization in intervention and control groups, do not want to participate at all[109] or (3) to achieve high adherence[30]. Finally, these studies have also questioned the ethical aspects behind RCTs by emphasizing the difficulty to convince a participant having given its consent that he or she will not benefit from the intervention[43]. For all these reasons and for this experiment to be fully integrated in the label "Vignoble Responsable ®", the present study was not conducted as a RCT insofar as the participants were free to choose allocation to either the intervention or the control group resulting in potential selection bias. Consequently, alternative designs of RCTs suggested by previous studies[108,109] were impossible to implement but should be taken into account in future investigations. Further, the limited number of participants did not permit subgroup analyses and analyses of potential confounders such as BMI, gender or job seniority[68-69]. Contrary to RCTs, we opted for an informed shared decision making[110] which has increased the number of participants[44]. Moreover, this intervention can be considered as the first necessary step to prevent WMSDs among a population of agricultural workers where such APA's interventions are lacking[111]. So far, common interventions have mostly focused on the ergonomics[8] by e.g. redesigning pruning shears[112,113] or work tasks[114,115]. Despite similar LBP intensity, the intervention group had a lower mean PPTs than the control group at baseline. It is not possible to know if this was a coincidence or if lower PPTs lead the workers to enter the intervention group. As the change in PPTs was used as an outcome, the PPT differences at baseline do not affect the conclusion[34]. At this point, however, this conclusion should be treated with caution assuming that there are asymptotic limits in PPTs. Indeed, to overpass this limitation, it is possible to assess pressure pain tolerance. Consequently, PPT and pressure pain tolerance could be combined in future studies[116]. More importantly, the minimal detectable change threshold of 100 kPa[68,69,99] was met after 8 weeks APA. Thus, the population size was small, but sufficient to detect changes in objective measures of the level of performance (endurance and flexibility) and pain sensitivity. Future studies should investigate the long-term effects of work-site and supervised APA program. Finally, it is important to recognise that the present study was not an intervention study aiming at reducing the occurrence of WMSDs but was rather implemented as a pilot study or a proof of concept aiming at evaluating the effects of a worksite supervised APA program. We are hence aware that assessing the efficacy of such a program would require reporting its cost-effectiveness, and consequently the analyse of the occurrence of WMSDs. Future studies assessing the effects of supervised worksite APA program on sickness absence and WMSDs are warranted.

Conclusions

This study has demonstrated an optimistic prediction of the adherence among a selected group of 25 eligible vineyard-workers in which 9 of them were volunteered to follow an 8 week APA program. This result can certainly explain the effects of this program in increasing trunk muscle endurance, flexibility as well as in decreasing mechanical pain sensitivity underlying the effects of the conducted work-site supervised APA program.

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APPENDIX 4. PAPER 4

Balaguier R, Madeleine P and Vuillerme N. Effectiveness and summative process evaluation of a worksite supervised intervention using adapted physical activity in viticulture: A non-randomized controlled trial. Submitted

Effectiveness and summative process evaluationof a worksite supervised intervention using adapted physical activity in viticulture: A non randomized controlled trial

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Abstract

Background Work related musculoskeletal disorders are considered as a crucial public health problem. This is especially true in agriculture's sectors such as in viticulture where effective prevention programs are needed. The objective of the present study was to perform an effectiveness evaluation and a summative process evaluation of a worksite supervised adapted physical activity (APA) intervention among vineyard-workers.

Methods Twenty-nine vineyard-workers employees in two French wine-producing companies volunteered to participate either in (1) the intervention (n=15) or (2) the control (n=14) group. The intervention group followed a 10-weeks supervised worksite APA intervention including (i) 15 minutes of warm-up before each working day and (ii) two weekly sessions of trunk strengthening and flexibility. The control group continued normal activity. Trunk muscle endurance and flexibility, pressure pain thresholds in the lower back region were measured for both groups before and after the intervention as indicators of its effectiveness. Moreover, at the end of the intervention, mixed methods, including interviews and questionnaires, were used to assess the adherence to the intervention and how it was perceived by the workers.

Results Effectiveness evaluation showed that, at the end of the intervention, changes in trunk muscles endurance and flexibility, pressure pain thresholds in the lower back region, were significantly larger for the intervention group. The summative process evaluation showed that overall levels of intervention's adherence and implementation quality were high. A full adherence was observed over the duration of the intervention.

Conclusions Participants reported high levels of satisfaction with the characteristics of the organization and of the intervention suggesting that a close and continuous collaboration between scientists, managers and employees can lead to increase the effectiveness of worksite APA intervention in viticulture.

Abbreviations

ACSM: American college of sports medicine

APA: Adapted physical activity

FTF: Finger to floor

PPT: Pressure pain thresholds

RM-ANOVA: Repeated measures –analysis of variance

SR: Sit and reach

Background

For several years, automation, robotics and mechanization have been developed to increase productivity in numerous sectors including agriculture. However, the human labor is still needed especially in viticulture where the work tasks required knowledge, attention and precision that no machine is, to date, able to master. The flipside of the coin is that, in viticulture as in other physically demanding sectors such as the healthcare [1,2] and the industry sector [3], vineyard-workers have a high prevalence of work related musculoskeletal disorders (WMSDs) [4,5,6]. Futhermore, numerous studies have reported that the risk of WMSDs is exacerbated in case of imbalance between physical capacities and work demands [7,8]. Thus, either decreasing work demands and/or increasing physical capacities appear to be relevant levers to be activated to limit the risk of WMSDs [7]. As this rational goes, we have recently implemented a worksite supervised adapted physical activity (APA) intervention among vineyard-workers [9]. This intervention was specifically designed to improve vineyard-workers' physical neuromuscular capacities, especially trunk muscle endurance and flexibility since these latter have been previously reported to be significantly lower in workers suffering from WMSDs located in the low back [10-13]. In our study, the effect of the APA intervention on vineyard-workers' mechanical pain sensitivity over the lower back region was also assessed [9]. Indeed, this semi-objective measurement of pain presents numerous advantages since it is sensitive to work exposure [14] and limits recall bias associated with subjective assessment of pain such as numeric or visual analogue rating scales [15]. The study showed significant increases in trunk muscle endurance and flexibility as well as a significant decrease in low back muscle pain sensitivity at the end of the supervised APA intervention [9]. However, although promising, this study only assessed the effectiveness of the APA intervention. The procedure employed did not include any process evaluation necessary to determine what could explain the success or failure of the intervention and to assess whether the intervention was delivered as planned [16,17]. These limitations hamper the generalization of the obtained results. In this sense, characteristics of the organization (i.e. management support, participation and engagement), characteristics of the intervention (i.e. frequency of sessions) and satisfaction with the intervention received (i.e. satisfaction with the methods employed, satisfaction with regard to the working conditions) are considered as major components to be integrated into the summative process evaluation [17]. Accordingly, concomitant effectiveness evaluation and summative process evaluation of the implemented worksite supervised APA intervention among vineyard-workers would provide relevant information concerning the former and future intervention [18,19].

Based upon our preliminary findings [9], the purpose of the present study was two-fold:

(1) To assess the effectiveness of a 10 weeks worksite supervised APA intervention on trunk muscle endurance and flexibility, low back muscle pain sensitivity of vineyard-workers ;

(2) To identify which factors may explain the level of effectiveness of the intervention, using a summative process evaluation.

Material and methods

Participants and design

The worksite supervised APA intervention was carried out among two wine-producing companies in the area of Bordeaux (France), namely the Château Larose-Trintaudon and the Château Pichon Longueville-Baron, over 10 consecutive weeks, from January to March 2015.

The inclusion criteria were: age between 18-55 years old, more than one year of seniority and full-time position. Participants were excluded if they have had back surgery within the last 12 months and if they were pregnant at the time of the study. Among the 43 vineyard-workers likely to participate in the present study, 14 did not volunteered to participate mainly because a lack of interest in the APA intervention, planning issue (APA sessions took place outside working hours) and lack of interest or need in physical training. All the volunteers were offered the possibility to follow or not the APA intervention. Thus, vineyard-workers that volunteered to participate in the APA intervention were included in the intervention group (N=15), while the remaining vineyard-workers were allocated to the control group (N=14, Figure 1). This present study followed a non-randomized design to ensure a large participation rate which is necessary to observe the intervention effectiveness [20], to increase adherence to the intervention [21] and to limit ethical problems specific to a working environment [22]. To improve the reporting quality, transparency and clarity of our intervention, the TREND checklist for non-randomized studies was followed [23]. Characteristics of the participants are presented in Table 1.

Figure 1. Flowchart of participants' recruitment.

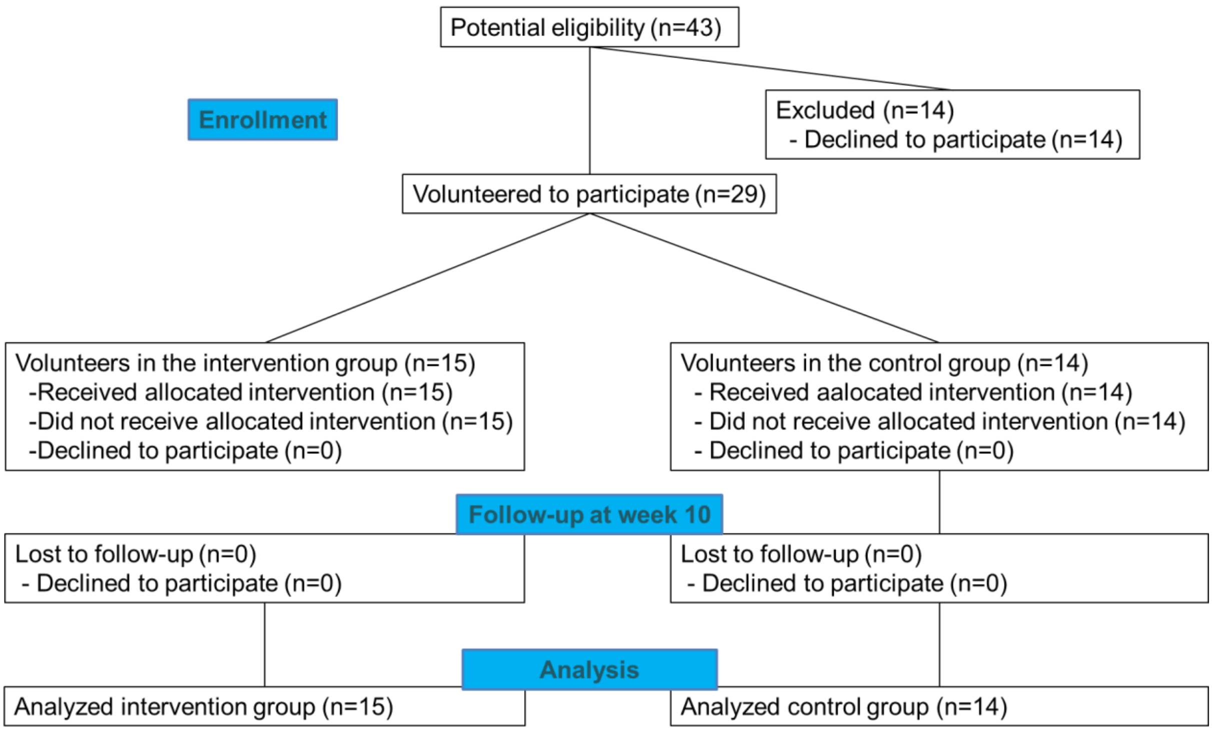

Table 1: Baseline characteristics of the participants

	Total (N=29)	Control (N=14)	Intervention (N=15)	p-value
Number of Women	13/29	7/7	6/9	
Age (years)	41.5 (10.6)	43.0 (11.8)	39.9 (9.4)	0.381
Height (cm)	168.0 (8.8)	168.8 (9.1)	167.3 (8.5)	0.628
Body mass (kg)	78.5 (16.0)	84.7 (17.3)	72.3 (14.7)	0.088
BMI (kg/m²)	27.8 (4.7)	29.7 (4.9)	25.8 (4.5)	0.025
Job Seniority (years)	18.5 (9.7)	21.4 (10.3)	15.6 (9.1)	0.268

Intervention

Vineyard-workers received a 10 weeks worksite supervised APA intervention that consisted of (i) warm-up during working hours and (ii) trunk strength and flexibility APA sessions during leisure time. This intervention, described in details below was supervised by two APA instructors.

Supervised warm-ups

Participants of the intervention group were required to follow a 15 minutes supervised warm-up at the beginning of each working day resulting in a total of 50 supervised warm-up sessions (5 working days a week during 10 weeks). The APA instructors made sure that the warm-up was feasible taking in consideration the workers' special equipment (e.g., boots, raincoat). Then, participants were asked to start their daily activities within 15 minutes following the warm-up to benefit as much as possible from the effect of the latter [24].

Supervised adapted physical activity training sessions

In line with the guidelines provided by the American College of Sports Medicine (ACSM) [25], participants of the intervention group were free to choose over two supervised training sessions of one hour per week over the 10 weeks APA intervention. However, a maximum of seven participants per APA training session was allowed. A typical APA training session consisted of 40 minutes of specific resistance and power training and 20 minutes of stretching targeting flexor, extensor and rotator trunk muscles. However, the type, the amount and/or the intensity of each exercise were adapted to each participant taking experienced pain or discomfort, level and progress in consideration [17]. To deliver attractive sessions, the instructors varied the type of exercises using several materials such as swiss-ball, medicine ball, elastic bands or dumbbells. For instance, dynamic and static exercises commonly implemented in WMSDs physical activity prevention interventions [26-30] consisted in abdominal crunches with/without swiss-ball, front and side bridge were performed during APA training sessions.

The control group was not offered any APA training sessions and was advised to continue regular physical activity.

Main outcome measures

The outcomes measured were assessed at two occasions, i.e. at the beginning (week 0) and at the end (week 10) of the APA intervention.

Effectiveness evaluation

Trunk muscle flexibility

Trunk muscle flexibility was assessed using the finger to floor (FTF) and the sit and reach (SR) considered as valid and reliable [31,32]. As described by Strand and colleagues [33], the FTF started with participants stood erect on 43 cm high specific box with fully extended legs. Then, the distance between the tip of the index finger and the ground was measured in cm during maximal trunk flexion. Then, for the SR, the participants were asked to sit on the floor with their legs fully extended and their feet placed together against a standardized box. A sliding device placed on the top of the box at 23 cm from the participant's feet (i.e. the 0 point) must be push forward as far as possible using both hands. The examiner measured the distance in cm between the 0 point and the arrival point on the sliding device [31]. For both FTF and SR tests, the best performance of three trials performed by participants was extracted for data analysis.

Trunk muscle endurance

Participants were asked to achieve two tests commonly used among workers suffering from WMSDs specifically designed to assess trunk flexor and extensor isometric endurance [34]. For trunk flexor endurance time, participants were seated on the floor with hips and knees flexed at 90°. Then, participants' feet were maintained on the floor by the examiner. A wedge with a 60° angle was placed behind the trunk of the participants [34]. A maximum holding time was fixed at 300 seconds once participant has removed his back from the wedge [34]. For trunk extensor endurance time, participants lying prone on an examination table with the iliac crests aligned with the edge of the table were asked to maintain the trunk parallel to the floor with the hands fold across the chest for a maximum duration of 240 seconds [34].

Pressure pain threshold over the lower back region

The PPTs were assessed using an electronic pressure algometer (Somedic Algometer type 2, Sollentuna, Sweden) over 14 anatomical locations of the low back region at a constant slope of 30 kPa/s and a 1 cm^2 probe. Three measurements were performed on each location and the mean of these three measurements was used for statistical analyses [35].

Summative process evaluation

The context of the intervention, dose delivered, dose received, fidelity, satisfaction of the intervention carried out and, suggestions for future intervention were the components included in the present summative process evaluation [16,17]. These six components are described below:

1. Context of the intervention

In this part, a description of organizational and environmental factors was included. Organizational factors were related to (1) the health policies of the companies, (2) the way the intervention was presented to vineyard-workers and (3) the way the management support was provided. Further, the environmental factors were related to (1) the APA training facilities and (2) the characteristics of the APA instructors [17,36].

2. Dose delivered

The dose delivered defined as the percentage of supervised warm-ups and sessions initially planned that were effectively implemented was measured [18].

3. Dose received

The dose received also called adherence to the intervention defined as the percentage of supervised warm-ups and sessions initially planned effectively achieved by the participants was measured [18].

4. Fidelity

Fidelity is defined as the extent to which the APA intervention was implemented as planned [37]. As recently proposed by Strijk and colleagues [36], fidelity was addressed using the following four topics: (1) whether group sizes (i.e. seven participants maximum) during training sessions were respected; (2) whether warm-up and training were offered in accordance with the time schedules initially planned; (3) whether the time allowed for warm-up and training has been respected by employees, employers and APA instructors and, (4) whether the training sessions were divided in 40 minutes training and 20 minutes stretching.

5. Satisfaction of participants

At the end of the intervention, participants of the intervention group were asked to rate their level of agreement with a series of statements concerning the quality of the intervention. A 5-point Likert scale was used for the responses [38]: 1=strongly disagree, 2=disagree, 3=uncertain, 4=agree, and 5=strongly agree. In line with previous studies [17,37], the following three characteristics of the worksite supervised APA intervention were assessed:

5.1 Characteristics of the intervention:

The participants were asked whether (1) the frequency of sessions was appropriate, (2) the content of sessions was adapted, (3) the examiners were attentive to special requests (e.g. discomfort, pain), (4) the APA intervention was entertaining and, (5) they would like to continue the APA intervention under the same conditions.

5.2 Characteristics of the organization:

Participants were asked whether (1) their opinion to design the intervention had been sufficiently taken into account, (2) the training equipment were appropriate, (3) they felt that the company had been interested in their well-being, (4) they felt motivated because they were part of a group and, (5) the APA intervention had allowed them to socialize with colleagues.

5.3 Satisfaction with the intervention

Participants were asked to indicate whether (1) they were satisfied with the APA intervention, (2) the APA intervention was effective to decrease LBP intensity, (3) the APA intervention was effective to increase their well-being, (4) the APA was effective to improve their working conditions and, (5) they would recommend the APA intervention to colleagues.

6. <u>Suggestions for a future APA intervention</u>

Participants were asked by the examiners whether they had suggestions for the implementation of a future APA intervention [39]. All the answers were transcribed verbatim and classified according to the following two distinct categories: suggestions regarding the characteristics of the worksite supervised APA intervention and the organization.

Statistical analyses

The statistical analyses followed an intention-to-treat analysis. A two-way repeated measure analysis of variance (RM-ANOVA) with the Holm-Šídák test that control for multiple comparison was then used for (1) all the outcome measures at baseline, (2) to locate difference over time between the intervention and the control group. Trunk muscle flexibility, trunk muscle endurance, PPT of the lower back region were used as dependant variables. Sessions (week 0 and week 10) and groups (control or intervention) were used as independent factors.

A priori calculations revealed that a sample size of 12 participants was required in each group to observe a 15% difference for outcomes of the effectiveness evaluation (trunk muscle endurance and flexibility and PPT) and to achieve a power of 0.80 with an alpha level set at 0.05.

A Spearman's correlation was run to assess the relationship between outcomes measures at baseline (week 0), changes and percentage of change over the 10 weeks APA intervention (week 10-week 0). The same analysis was performed to assess the strength and the direction of the relationship between changes in PPT (week 10-week 0) and changes in outcome measures over the 10 weeks APA intervention (week 10-week 0). Spearman's rho coefficients were interpreted according to Sullivan and Feinn[40]: rho between 0.20-0.49 is considered 'small', rho between 0.50-0.79 is considered 'moderate' and rho between 0.80-1.00 is considered 'large'. Level of significance was set at $P<0.05$. Results are expressed as mean (95% confidence interval [CI] or (SD)).

Results

Effectiveness of the worksite supervised APA intervention for vineyard-workers

At baseline, no significant differences were observed between the control and the intervention group, except for the PPT (significantly lower PPT for the intervention compared with the control group). Mean (95% CI) and changes in trunk flexibility and endurance tests, PPT are presented in Table 2.

Trunk muscle flexibility

Changes from week 0 to week 10 were significantly larger for the intervention compared with the control group for both the FTF and SR tests. At week 10, a significantly higher performance was reported for the intervention compared with the control group ($P<0.001$). For the intervention group, a moderate negative correlation was also found between the FTF performance measured at week 0 and the evolution of the FTF (Figure 2A). A large negative correlation was also depicted between the SR performance measured at week 0 and the percentage of evolution of the SR performance (Figure 2B).

Trunk muscle endurance

Similarly, changes from week 0 to week 10 were significantly larger for the intervention compared with the control group for both the trunk flexor and extensor endurance tests. At week 10, a significantly higher performance was reported for the intervention compared with the control group ($P<0.001$). For the intervention group, a large negative correlation was found for trunk extensor endurance (Figure 2C) performance at week 0 and the percentage of evolution. A large negative correlation was also detected for trunk flexor (Figure 2D) performance at week 0 and the percentage of evolution.

Pressure pain thresholds of the lower back region

The PPT mean difference from week 0 to week 10 was significantly larger for the intervention compared with the control group ($P<0.001$). For the intervention group, a small positive correlation was found for PPT measured at week 0 and the percentage of evolution of the PPT (Figure 2E).

Summative process evaluation of the worksite supervised APA intervention for vineyard-workers

1. Context of the intervention

(1) Organizational factors

Both companies were particularly involved in their employees' well-being and health. For instance, the Château Larose-Trintaudon has developed over 15 years a label named "Responsible Vineyard" that pay attention to employees' motivation and well-being. In this sense, more than 90% of employees of both Châteaux have followed educational programs aiming at developing their skills, improving their qualifications and health.

The intervention was presented as follows. First, approx. 5 months before the intervention, the aim of the study including findings from previous APA program were presented to all the vineyard-workers [9]. Then, the APA intervention organization (i.e. schedule for warm-ups, APA training sessions, and evaluations) was presented by the management to all volunteers (i.e. volunteers from the intervention and control group) two months before the intervention.

(2) Environmental factors

Warm-ups and training sessions were supervised separately. For both companies, the supervised APA training sessions were delivered by two instructors in a training room located at the workplace. The two APA instructors intervened as consultant. Both instructors hold a master degree in Physical and Sports Activities Science and Techniques (STAPS) - specialty Adapted Physical Activities and Health.

2. Dose delivered

The dose delivered was 100%, i.e. that the two APA instructors delivered all the supervised APA training sessions initially planned.

3. Dose received

The dose received or the adherence over the 10 weeks APA intervention was 100%. Furthermore, no participants reported adverse events.

4. Fidelity

The maximum recommended number participants per supervised APA training session (n=7) had never been exceeded. The warm-ups and training sessions were offered as initially planned. Concerning warm-ups, APA instructors reported that during the first two weeks, the duration lasted approx. 20 minutes. The main reason given by the APA instructors was the need to properly explain and demonstrate the exercises.

One session at the Château Pichon-Baron was implemented differently than initially planned. The APA instructors found the vineyard-workers very exhausted and decided to implement 60 minutes of stretching instead of the 40-20 minutes of training-stretching.

5. Satisfaction of participants with the worksite supervised APA intervention

The results of satisfaction are presented in Table 3.

5.1 Characteristics of the worksite supervised APA intervention

The participants' mean (SD) scores ranged from 4.3 (0.5) to 4.8 (0.4) over the 5 points Likert scale. Most of the participants found that the APA intervention was adapted to their level and their special request (4.3 (0.5)) since most of them reported that they would like to continue to this intervention under the same conditions (4.5 (0.6)). All the participants found the APA sessions entertaining (4.8 (0.4)).

5.2 Characteristics of the organization

Participants' mean scores ranged from 4.0 (0.5) to 4.6 (0.5). One participant reported that the training equipment was inappropriate.

5.3 Satisfaction with the intervention

Participants' mean scores ranged from 4.3 (0.6) to 4.5 (0.5). All the participants were satisfied with the intervention and reported that the intervention was effective in decreasing their LBP intensity (4.4 (0.5)) and increasing their well-being (4.5 (0.5)) as well as improving their working conditions (4.5 (0.5)).

6. Suggestions for a future APA intervention

6.1 Suggestions regarding the characteristics of the intervention:

Ten participants (out of 15) pointed out that future APA intervention should be (1) extended over a longer period and (2) implemented as an adapted physical preparation before the performance of all physical demanding tasks. As title of example, one worker mentioned:

"It would be nice to benefit from the APA sessions all over the year, especially before starting winter activities. In fact, it would be useful to train our muscles to be ready from November activities."

6.2 Suggestions regarding the characteristics of the organization

Fourteen (out of 15) participants mentioned they would like to continue to benefit from this intervention under the same condition (training equipment, APA training rooms). For instance, one of the participants made the following quotation:

"The training equipment was adapted and sufficient for the intervention. Furthermore, we have performed exercises with training equipments that we did not know before. Training with swiss-ball and dumbells was very nice."

One participant has suggested the use of weightlifting machines to complete the material:

"The content was adapted to my work and my capacities. The possibility to choose the slots was useful, especially when one has children. However, it would be nice to practice with weightlifting machines to vary even more the exercises."

Table 2: Mean (95% Confidence Interval) for trunk flexibility and endurance tests, for pressure pain thresholds (average of the 14 locations) according to groups (Control and Intervention) and sessions (weeks 0 and 10). Significant differences between the two groups are expressed as follows: *: P < 0.05 ; **: P < 0.01 ; ***: P < 0.001

	Week 0			Week 10			Difference Week 10 – 0		Percentage of change between week 10 and 0		
Outcomes	**Control**	**Intervention**	**ES**	**Control**	**Intervention**	**ES**	**Control**	**Intervention**	**Control**	**Intervention**	**ES**
Finger to floor (cm)	49.3 (46.0 – 52.6)	42.4 (38.6 – 46.2)	0.7	51.8 (48.3 – 55.4)	37.1*** (34.4 – 39.8)	1.7	2.5 (-0.3 – 5.3)	-5.3*** (-7.0 - -3.5)	5.1 (-3.1 – 13.2)	-12.5*** (-7.8 - -17.0)	1.2
Sit and reach (cm)	24.5 (22.1 – 26.9)	30.4 (27.7 – 33.0)	0.8	23.4 (20.9 – 26.0)	33.2** (31.1 – 35.3)	1.5	-1.1 (-2.2 – 0.1)	2.84*** (1.6 – 4.1)	-4.3 (-11.9 – 3.2)	9.4*** (0.7 - 18.0)	1.2
Trunk extensor endurance (sec)	55.7 (39.6 – 75.4)	81.9 (66.1 – 99.6)	0.5	57.1 (37.7 – 80.2)	145.5*** (130.4 – 160.7)	1.7	1.4 (-13.9 – 16.7)	63.7*** (50.3 – 77.0)	2.5 (-20.6– 25.6)	75.6*** (12.5- 138.7)	1.6
Trunk flexor endurance (sec)	106.2 (66.5 – 145.9)	117.7 (83.5 – 152.0)	0.1	104.8 (64.3 – 145.3)	240.9*** (209.5 – 272.3)	1.4	-1.4 (-12.9 – 10.0)	123.1*** (93.2 – 153.0)	-1.3 (-28.3 – 25.6)	104.6*** (35.0- 174.2)	2.2
Pressure pain threshold (kPa)	572.3 (486.8 - 657.7)	462.7*** (383.8 - 541.6)	0.5	583.4 (488.0 - 679.0)	576.8 (487.0 - 666.6)	0.1	11.2 (-3.2 - 25.6)	114.1*** (98.8 – 129.4)	1.9 (0.2 – 3.2)	24.6*** (5.4 – 43.9)	3.6

Figure 2. Correlation between performance at week 0 and the percentage of change between week 0 and week 10 for the finger-to-floor test (A), the sit and reach test (B), the trunk extensor endurance test (C), the trunk flexor endurance test (D) and for the pressure pain thresholds over the lower back region (E) for the intervention group. *: P < 0.05 ; **: P < 0.01 ; ***: P < 0.001.

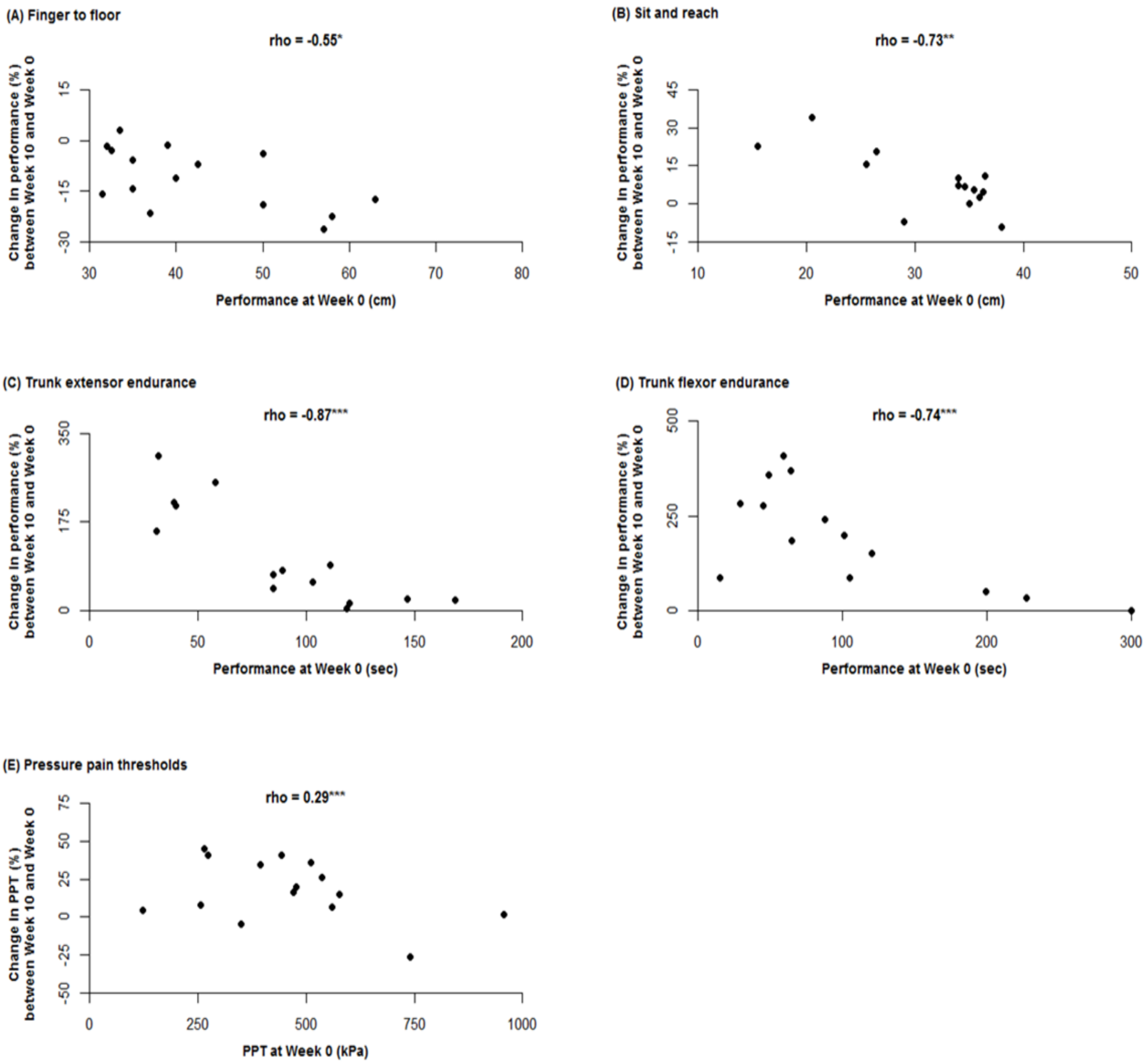

Table 3: Results of the summative process evaluation of the worksite supervised APA intervention for vineyard-workers (n=15). Number (and percentages) of respondents describing their appreciation of (1) the characteristics of the APA intervention, (2) the characteristics of the organization and (3) the satisfaction with the APA intervention on a 5-point Likert scale.

		Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Mean	SD
1	**Characteristics of the worksite supervised APA intervention**							
1.1	Frequency of session was appropriate	0 (0.0%)	0 (0.0%)	0 (0.0%)	11 (73.3%)	4 (26.7%)	4.3	0.5
1.2	The content of sessions was adapted to the participants' level	0 (0.0%)	0 (0.0%)	0 (0.0%)	11 (73.3%)	4 (26.7%)	4.3	0.5
1.3	The APA instructors were attentive to special requests (i.e. discomfort and pain)	0 (0.0%)	0 (0.0%)	0 (0.0%)	8 (53.3%)	7 (46.7%)	4.5	0.5
1.4	Participants have found the APA intervention entertaining	0 (0.0%)	0 (0.0%)	0 (0.0%)	3 (20.0%)	12 (80.0%)	4.8	0.4
1.5	Participants would like to continue to benefit from the APA intervention under the same conditions	0 (0.0%)	0 (0.0%)	1 (6.7%)	6 (40.0%)	8 (53.3%)	4.5	0.6
2	**Characteristics of the organization**							
2.1	Participant' opinions to design the APA intervention has been sufficiently taken into account	0 (0.0%)	0 (0.0%)	0 (0.0%)	9 (60.0%)	6 (40.0%)	4.4	0.5
2.2	The material conditions were appropriate	0 (0.0%)	1 (6.7%)	0 (0.0%)	10 (66.7%)	4 (26.7%)	4.1	0.8
2.3	Participants have felt that the company has been interested in their well-being	0 (0.0%)	0 (0.0%)	2 (13.3%)	11 (73.3%)	2 (13.3%)	4.0	0.5
2.4	Participant have felt motivated because they were part of group	0 (0.0%)	0 (0.0%)	0 (0.0%)	8 (53.3%)	7 (46.7%)	4.5	0.5
2.5	The APA intervention have allowed participants to establish links with colleagues	0 (0.0%)	0 (0.0%)	0 (0.0%)	13 (86.7%)	2 (13.3%)	4.1	0.4
3	**Satisfaction with the APA intervention**							
3.1	Participants were satisfied with the APA intervention received	0 (0.0%)	0 (0.0%)	0 (0.0%)	6 (40.0%)	9 (60.0%)	4.6	0.5
3.2	Participants have felt that the APA intervention has improved their working conditions	0 (0.0%)	0 (0.0%)	0 (0.0%)	8 (53.3%)	7 (46.7%)	4.5	0.5
3.3	Participants have felt that the APA intervention has improved participants' well-being	0 (0.0%)	0 (0.0%)	0 (0.0%)	7 (46.7%)	8 (53.3%)	4.5	0.5
3.4	Participants have found that the intervention was effective to decrease LBP intensity	0 (0.0%)	0 (0.0%)	0 (0.0%)	9 (60.0%)	6 (40.0%)	4.4	0.5
3.5	Participants would recommend the APA intervention to others vineyard-workers	0 (0.0%)	0 (0.0%)	1 (6.7%)	9 (60.0%)	5 (33.3%)	4.3	0.6

Discussion

The objective of the present study was to perform concomitantly an effectiveness and a summative process evaluation of an implemented worksite supervised APA intervention among vineyard-workers. Taken together, the present findings showed that a close and continuous collaboration between scientists, managers and employees can lead to increase the effectiveness of worksite APA intervention in viticulture.

The effectiveness of the intervention was reflected in the significant improvements reported in the physical capacity tests, i.e. trunk endurance and flexibility tests. Indeed, the intervention group significantly increased their endurance time of trunk extensors and flexors muscles by more than 70% and 100%, respectively and trunk muscles flexibility by approx. 10%. Conversely, no significant changes were observed in the control group. Mannion and colleagues [41] have hypothesized that these improvements could partly reflect a better muscular activation, potentially altered by repetitive motions and bended postures [42] commonly performed by vineyard-workers [43,44]. These results can also be explained by the duration of the intervention (i.e. 10 weeks) and the frequency of the APA sessions (i.e. 2 times per week) as highlighted by Garber and colleagues [25]. At this point, we must admit that comparing these results with the existing literature remains difficult due to differences in populations, exercises, duration and frequency of training sessions [45,46]. Nevertheless, the results of the present study confirmed our previous findings, i.e., increase by 100% and 15% of trunk muscle endurance and flexibility after an 8 weeks APA intervention involving two weekly supervised APA training sessions per week [9]. Similar trends in trunk muscle endurance and flexibility have also been reported among office-workers and assembly line workers [28,47].

Pressure pain sensitivity is commonly assessed over the low back region [48]. At baseline, the intervention group reported lower PPT than the control group. Interestingly, this result suggests that vineyard-workers with higher pain sensitivity could be more prone to be willing to participate in the APA intervention in line with our previous findings [9]. At baseline, all participants had lower PPTs than those reported by Farasyn and Meeusen [49]. These PPT values could reflect hyperalgesia in the low back, a common phenomenon observed among patients with WMSDs [50]. Of note, the APA intervention was effective to decrease mechanical pain sensitivity, i.e. PPTs increased in the intervention group. We have recently reported that the minimum change necessary to observe a real difference in PPT over the low back region among vineyard workers is approx. 110 kPa [35]. One should note that the PPT changes reported in the present study were higher than this threshold (i.e. 115 kPa). Consequently, the difference between week 0 and week 10 cannot be attributed to measurement error confirming the effectiveness of the APA intervention on mechanical pain sensitivity. In agreement with our findings, increased PPT have also been reported after 10 weeks involving three weekly sessions of supervised specific strength training among office-workers with neck complaints [45,51]. Taken together, these findings point towards a decrease in mechanical pain sensitivity and suggest exercise-induced mechanical hypoalgesia [52].

To improve the effectiveness of further interventions, we also determined which participants benefited the most from the APA intervention. Firstly, we found a significant moderate negative correlation (i.e. $0.5<\text{rho}<0.7$) between the performance at baseline and the improvement observed at week 10 concerning PPT and a large negative correlation (i.e. $\text{rho}>0.7$) for neuromuscular capacities evaluations. These correlations indicated that the observed post-intervention improvements were greater for the participants who had lower performance or score at baseline. Similar findings have been reported by Ferreira and colleagues [53] and Unsgaard-Tøndel and colleagues [54] after training interventions among non-specific low back pain individuals. Interestingly, if one considers that participants with the poorest performance at baseline are those with the highest risk of LBP [55], our study suggests that the implementation of a 10 weeks worksite supervised APA intervention seems particularly effective among participants with highest risk of developing LBP. Moreover, as self-efficacy defined as the extent to which an individual believes in its capacities to carry out a behaviour [56] is an important facilitator to motivate participants over time [57,58], these results could be used in further investigation to encourage new participants, specifically those with low trunk muscle endurance and flexibility, to take part in this type of APA intervention.

We also implemented a summative evaluation process to address further the question of the effectiveness of the APA intervention. Firstly, it is well accepted that workplace physical activity benefits depend on the intervention adherence, i.e. the dose received [59,60]. This supervised worksite APA intervention resulted in full adherence in contrast to the 35-85% reported elsewhere [57,60]. This finding can partly be explained by the fact that only volunteers took part in the present study [61]. Actually, 14 vineyard workers (out of 29 volunteers) refused to join the intervention group due to three main reasons : lack of interest for the APA intervention, (ii) APA sessions planned during leisure time and (iii) they perceived themselves as physically active. The remaining 15 vineyard workers volunteered to participate and fully adhered to the APA intervention. A number of factors most likely played a role in this observation. The context i.e. companies' health policies, support from management, characteristics of the APA instructors are key factors in its adherence [62,63]. It is probable that the policies ensuring occupational health and safety at the workplace and promoting health and well-being in these two wine-producing companies did constitute major facilitators of the intervention [17]. In the same vein, support from senior and middle managers as it occurred in the present study appears to be strongly associated with high adherence rate [17]. Another key element concerning the full adherence stems from the intervention design (i.e. schedules and content of the APA sessions as well as training equipment/facilities). For instance, the frequency of sessions and training facilities were perceived as appropriate by the vast majority of the vineyard-workers. Moreover, most of the participants of the intervention group suggested increasing the duration of the APA intervention to be physically fit for winter activities. Only one participant found the training equipment inappropriate and suggested to use weightlifting machines in the future APA intervention. Amireault and colleagues [64] have also pointed out that the effectiveness of an intervention depends on its adherence over time. Conversely, when training frequency is unsuitable or when flexibility in choosing sessions' slot is limited, lower adherence is observed [18]. Another facilitator to be considered is that the APA intervention empowered social interaction between participants. It is important to note that during pruning activity, vineyard-workers spend most of their working time alone between the rows of vines. The training sessions performed in group of up to seven vineyard-workers offered the opportunity to develop links and social interaction between colleagues. Indeed, Brinkley and colleagues [65] and Andersen and colleagues [66] have reported that participation in workplace APA intervention is effective to improve team work, team values and communication between colleagues. Many times, vineyard-workers have also mentioned that the training sessions were the occasion to address other issues than work facilitating daily communication. Finally, the role of the APA instructors should not be underestimated. In this sense, the instructors adapted the proposed exercises to the participants' capabilities and expectations in agreement with previous studies [60,62]. This contributed to explain that the participants reported the session contents adapted to their physical capacities preventing fatigue, discomfort or injuries (no adverse effects reported). Second, the APA instructors paid a particular attention to use different training items and propose more than 10 entertaining exercises since one barrier to adherence is exercises' repetitiveness [18].

Study limitations

The non-randomised design used in the present study is certainly a limitation. Indeed, randomized controlled trial is considered as a gold standard to assess the effect of an intervention [67]. However, in a workplace context, numerous authors have pointed out the difficulties to implement such a design [37,68] in line with the TREND statement [23]. At the top of the mentioned barriers, not offering all employees the possibility to participate in an intervention can be considered as unethical and unfair [68]. Consequently, alternative solutions such as cluster randomized or stepped wedge designs have been increasingly implemented at the workplace [26,57,69,70]. In the present study, a change in exposure observed after March in the activities performed by the vineyard-workers at work prevented us at the moment from setting up such a design. Moreover, in a sector where initiatives to promote physical activity are still lacking, having a small but dynamic, involved and proactive volunteers is considered a key element towards effective and sustainable interventions. Finally, in the summative process evaluation, all the vineyard-workers mentioned that the APA intervention contributed to improve their working environment, general health and well-being at work. When such improvements are reported by workers, effects on absences for sick leave, work absenteeism, productivity and, costs related to illness or injury can be expected [71]. However, conducting a cost-effectiveness analysis requires a high plan design [72,73] and implies a sufficient duration of interventions, i.e. at least 1 to 3 years [74]. In the years to come, conducting such analyses seems essential to assess in depth the effectiveness of such interventions.

Conclusion

The present study showed that a 10 weeks worksite supervised APA intervention was effective to increase trunk muscle endurance and flexibility and PPT over the lower back region among 29 volunteer vineyard-workers from two vine-companies. Further, the findings revealed that targeting participants with low physical capacities can be particularly relevant since they can be considered with higher risk of developing WMSDs in the lower back and are likely to benefit the most from an APA intervention. In a complementary and convergent manner, the summative process evaluation underlined that the APA intervention was implemented as initially planned with regard to the doses delivered and received. The summative process evaluation also delineated that the context of the intervention was prone to increase its effectiveness and that the vast majority of the participants were satisfied with the intervention received. Taken together, these results (1) confirmed that an APA intervention can be integrated as a promising strategy to prevent WMSDs of the low back in wine-producing companies' health policies and (2) that further studies are needed to assess its' long term effectiveness.

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SUMMARY

Work related musculoskeletal disorders (WMSDs) affecting the low back are conditions highly prevalent in viticulture. Their multifactorial origin makes their prevention difficult and still challenging. The first objective of this PhD thesis was to conduct a field ergonomic work exposure analysis investigating the location and severity of WMSD symptoms and measuring the kinematics during pruning activity. The second objective took its assets in the above mentioned analyses and consisted in the conception, implementation and evaluation of a workplace supervised adapted physical activity (APA) program for the prevention of WMSD of the low back among vineyard-workers. As a whole, this PhD thesis demonstrated that, based on a field ergonomic work exposure analysis, a supervised workplace APA program can be considered a promising solution to prevent WMSDs and can be integrated as one component of wine-producing companies' health policies already including ergonomic approaches.

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